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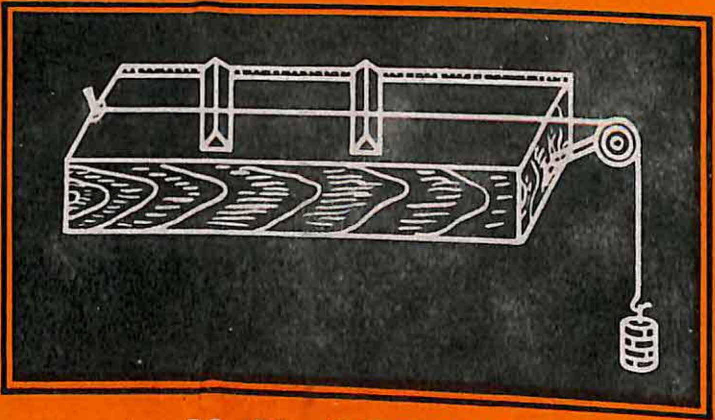
Practical PHYSICS

VOL. II



K. K. MOHINDROO

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PRACTICAL PHYSICS

Volume II for Class XII

[STRICTLY ACCORDING TO THE NEW SYLLABUS PRESCRIBED BY THE CENTRAL BOARD OF SECONDARY EDUCATION, NEW DELHI, IN PRACTICAL PHYSICS FOR CLASS XII]

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PREFACE TO THE FIRST EDITION

"Experiment is the interpreter of nature. Experiment never deceives. It is our judgement which sometimes deceives itself, because it expects results which experiment refuses."

—Leonardo da Vinci

We are living in a modern age. A complete and generous education is a prime necessity now, when the competition for existence is growing every moment and the struggle for international supremacy is threatening the very civilization.

We are moving fast, in fact too fast. While the modern inventions have made our actions responsive to touch, the man of tomorrow must know how to keep pace with them. The future man is being manufactured in our class-rooms and laboratories now. To keep pace with his future environments, he must develop in him the technique of maximum output with the minimum of time, energy and material. The present day education ought to help him to acquire that. *'Plus Two Experimental Physics*, as a part of education, has a primary duty in this direction.

. This book presents a text on experimental Physics intended to meet the needs of Class XII students opting for *new Physics courses* at the Plus Two stage of 10 + 2 year pattern of education. The book has been written after my long and direct contact of 30 years with the students of Physics. In this period of contact I had the previlege to come across the actual problems confronting students in the laboratories.

The broad objectives of the new experimental course are :

(1) to develop curiosity of the students.

(2) to learn scientific method and develop creative ability through experiments and investigations, and

(3) to emphasise practical work in physics through interesting experiments, both short and long, several of which can be done by using low cost items easily available.

The aim of the book is, however, not to replace the teacher. The teacher in the laboratory can always train a young pupil on proper lines; the present book is to serve as an aid for this purpose.

The book is written in a simple and lucid language and is strictly according to the new syllabus prescribed by the Central Board of Secondary Education, New Delhi. **In the book, greater emphasis has been laid on the experimental, rather than the theoretical aspect of each experiment.** Of course, the theory and the principle of each experiment essential for its successful performance has been duly described and discussed. While describing the steps of procedure for the experiment logically and systematically, attention has been pointedly drawn to the important precautions to be observed at this stage. The record of observations is an important part of the procedure of the experiment. For this purpose simple and self-explanatory tables have been drawn and, by way of illustration, actual readings have been inserted in some experiments and steps of calculation have been methodically shown. Whatever and whenever possible, graphical methods have been introduced.

Figures of instruments and diagrams required for the experiments have been neatly and accurately drawn. They are mostly sectional, simple and their important components have been labelled. Various vital points for drawing scientifically correct conclusions from the observations of an experiment have been discussed in sufficient detail in the "INTRODUCTION".

A special feature of this book is that at the end of every experiment there are specimen **Oral Questions with their Answers** (which are usually asked at the time of Board Practical Examinations) concerning the experiment whereby the student is encouraged to test his grasp of the principles. This has been done with a purpose to lead the student to a better understanding of the experiment as a whole and thus to face the Practical Examinations with confidence.

I am thankful to serveral of my colleagues and friends and former students for their suggestions, criticism and help in the preparation of the book. I shall feel greatly obliged to those readers who will bring to my notice the shortcomings of the book and forward to me their suggestions for its improvement.

The book fully meets the requirements of the changed syllabus in Practical Physics for Class XII of Senior School Certificate Examiation of the Central Board of Secondary Education, New Delhi.

The author wishes to express his special appreciation to the publishers, M/S PITAMBAR PUBLISHING COMPANY for their good work and painstaking efforts in bringing out this book in a short period of time.

K.K. MOHINDROO

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Latest syllabus in **PHYSICS PRACTICAL** for class XII prescribed by the Central Board of Secondary Education, New Delhi for All India & Delhi Senior Secondary Examinations.

In all 16 experiments, 8 from each section, are to be performed in the class. Students will be required to undertake two experiments in the Board examination. Distribution of marks will be as follows :

Viva	5 marks	
Records	6 marks	
Investigatory Projects	5 marks	
Two Experiments	14 = (7 × 2) marks	Total : 30 marks

Section A

1. To study current-voltage relationship (Ohm's Law) using an ammeter and voltmeter.
2. To use a Wheatstone's bridge (metre-bridge) for finding an unknown resistance.
3. (A & B) To study the laws of combination of resistances using meter bridge/post office box.
4. To study the temperature dependence of a resistance (Thermister/ iron wire).
5. To determine the specific resistance of the material of a wire using a meter bridge.
6. To compare the emf's of two primary cells by potentiometer.
7. To determine the internal resistance of a primary cell by potentiometer.
8. To study the equivalance of electric and heat energy.
9. To determine the e.c.e. of copper using a copper voltameter.
10. To determine the resistance of a galvanometer by half deflection method and convert it into an ammeter and voltmeter of suitable range.
11. To study the charging and discharging of a capacitor.

Section B

1. To plot the magnetic field of a straight conductor and earth together.
2. To plot the magnetic field of a bar magnet and earth together.
3. To use tangent galvanometer for determining the value of H.

4. & 5. To find the value of v for different values of u in case of a concave mirror and a convex lens for finding f by plotting of graphs between u and v; 1/u and 1/v.

6. To find the focal length of a concave lense using a convex lens.
7. To find the focal length of a convex mirror using a convex lens.
8. To determine the refractive index of a material of a convex lens.
9. To study the variation of the angle of deviation with the angle of incidence using a glass prism.

10. & 11. To use a spectrometer for finding refractive index of the material of a prism and for the liquid using a hollow glass prism.

12. To make a simple double slit and find the wave length of red light by it.

INTRODUCTION

(Accuracy, Errors, Graphs and Units)

"Nature is ever making signs to us : she is ever whispering to us the beginning of her secrets; the scientific man must be ever on the watch, ready at once to lay hold on nature's hint, however small; to listen to her whisper, however low." —*M. Foster*

In the world around us various natural phenomena are constantly occurring. The sun rises and sets causing the succession of day and night. The seasons follow in regular cycles. The weather undergoes constant changes. The stars, lightning, rainbows and many other things we notice have been the cause of wonder and curiosity to man.

Gifted with an inborn intelligence, man has constantly tried to know the cause of the natural phenomena and the natural changes, which he observes in his life. This enquiry carried on through generations, has lead to a considerable amount of knowledge which we call Science. It is a Latin word which means 'to know'. In a general way, therefore, knowledge of all kind is included in science, but in the ordinary accepted sense, *Science is that branch of knowledge which studies nature, its working and its laws*. Knowledge connected with non-living bodies or inert masses which go to make up the world is called the Physical Science but *physics concerns itself with an investigation of matter and energy*.

Experiments. The growth of science has been very rapid in the last three hundred years. In this period, the experimental study of nature has been persued and it has proved extremely fruitful in revealing new knowledge, and as a means of deciding different theories. Galileo (1564-1642) may be called the father of experimental sciences. A process of taking observations under conditions deliberately arranged so as to answer a particular question is called an **experiment.** The object of performing an experiment of Physics in the laboratory is generally either to determine the value of some constant, *e.g.*, acceleration due to gravity, value of earth's horizontal field, or to verify some principle *e.g.*, Boyle's law, laws of refraction. An experiment affords the opportunity to a student to familiarise himself with various instruments about which he reads in theory. It further provides him with a golden chance to learn the habit of systematic observations and methodical procedure and thus train him in "*How to do things honestly, efficiently and regularly*".

Intelligent work is more important than good results; students who try to change their observations simply for getting accurate; results, do not work with the true spirit of a scientist.

Accuracy of Observations

The fact that the accuracy of the final result is determined by the accuracy of the individual measurements and that all the measurements should be taken with utmost care is true but sometimes we may err on the other side, *i.e.*, we may waste time in taking some reading too accurately. It is no use taking one observation to a much higher degree of accuracy than the other observations because it will not make the result more accurate. The accuracy of the result is the same as that of the least accurate observation.

The strength of a chain is known by its weakest link and so a good observer will always look at the weakest spot in his measurements. He would take the quantities one by one as they occur in the formula and would calculate the % error involved in each measurement with the instrument provided. Those quantities which involve large % error would need his keen attention and he would use, if possible, an instrument of greater precision for their measurement, and thus bringing them to the level of the other measurements.

In an experiment all observations are not equally important and the student should have a good idea of their relative importance so that the accuracy in a particular observation is not unnecessary pushed up. More attention should be paid to most important observations.

For example, consider a wire of correct diameter 1·00 *mm*. If by mistake it is found as 1·02 *mm*, the error of observation is 20%. Its correct and observed area of cross-section (πr^2) is 0·786 *sq. mm* and 0·817 *sq cm* respectively and the error in its measurement is 4%. If the radius is raised to 4th power, the error would become 8%. *The % error in the result is as many times greater as is the power to which the quantity is raised. So the quantity having the highest power should be measured with highest precision than the rest.*

Accuracy Ordinarily Expected in a Measuring Instrument

The accuracy of a single observation made with a measuring instrument depends upon the instrument as well as on the skill and care with which the observation is made. Assuming that the instrument is correct and that reasonable care has been taken in carrying out the measurement we may expect that the error of a single observation lies within the limits mentioned below :

Instrument	*Error*
Metre-stick (in *mm*)	1 *mm*
Vernier Callipers (Vernier Constant = 0·1 *mm*)	0·1 *mm*

Instrument	*Error*
Screw Gauge (Least Count = 0·01 *mm*)	0·01 *mm*
Spherometer (Least Count = 0·01 *mm*)	0·005 *mm*
Physical Balance (Sensitivity 1 *mg* per small division)	2 *mg*
Physical Balance (Method of oscillation)	1 *mg*
Thermometer (0·5°*div.*)	0·2°C (Using eye-estimation)
Thermometer (0·1°C *div.*)	0·05°C (Using eye-estimation)
Stop Watch ($\frac{1}{5}$ *s*)	$\frac{2}{5}$ *s*

The table is meant to give the student a rough idea of the limit of accuracy and should not be taken exact.

The observations should be recorded with the same degree of accuracy as the measuring instrument permits. For example, in the measurement of the temperature with a half degree thermometer it is foolish to put down the reading correct upto a second place of decimal say 26·69, because the least count of the thermometer is $\frac{1}{2}^{0}$ and at the most we can estimate upto $\frac{1}{10}$th of degree. Thus with such thermometers the observations of temperature should be recorded only upto the first decimal place.

It is commonly used to denote the reliability of the indication of a measuring instrument, when taking an observation, fraction of the smallest divisions may be estimated and recorded as far as possible. For instance, *a length found to be exact 9 cm should be recorded as 9·0 cm to indicate that nearest mm has been read. Similarly a temperature reading found to be exactly 25° should be registered as 25·0° to indicate that 10ths have been read and so far the mass if it is 76·5 g, it should be noted as 76·500 g to indicate that correct upto a mg has been weighed.*

You may find that in spite of all your efforts, there may be some difference between your calculated result and the standard value from physical constant tables. Absolute error is the difference between calculated result and the standard value. Remember, it is not the absolute error, but the percentage error which is the ratio of the absolute error to the total magnitude of the quantity multiplied by 100 that determines the accuracy of a measurement. If, for example, a student gets the value of *g* as 960 instead of 980, he is terrified by this large difference of 20 which is the absolute error, but he feels satisfied when he gets 0·000013 as the coefficient of linear expansion of iron in place of 0·000011. The first result, however, is only $\frac{20 \times 100}{980}$ or 2% approximately low, whereas in the second there is an error of $\dfrac{\cdot 000002 \times 10}{\cdot 000011} = 18\%$. *If you find that your result does not tally with the standard value, do not cook it by changing your observation or writing fictitious reading or by doing wrong calculations but try to find out the cause of errors and state it in the Sources of Error.*

ERRORS

The quantities, which the students generally measure, may be mass, length, time, volume, temperature, current, potential difference, degree, etc. In all these cases observation finally reduces to the reading of a scale or noting the coincidence between two marks. As the personal judgement of the observer is employed in estimating the coincidence between two marks or in recording the position of a pointer which is between two marks of a scale, so an error is inevitable. Besides, slight changes in experimental condition (*e.g.*, small changes of temperature, pressure, voltage, etc.) may occur during the experiment and lead to small uncertain errors.

1. Random Errors. The errors arising out of small changes in the experimental conditions and the personal judgement of the observer are known as random errors. When random errors are due entirely to chance, and not due to any personal bias on the part of the observer, they are likely to be positive as well as negative. When an observation gives a higher value than the true one, the error in the observation is said to be positive. *Large random errors due to chance are less likely to occur than the small.* If a large number of observations of the same quantity is made, it is likely that most of them will have small errors, each one of which has a much chance of being positive as negative. *Hence the arithmetic mean of several readings is likely to be closer to the true value than any one of the individual readings.*

Values to be Rejected. Sometimes it happens that one of the observed values differs rather widely from the rest. Should it be included in taking the arithmetic mean? If the relative difference, when calculated in %, is very large, it should be certainly rejected. But unfortunately the difference is not always so pronounced as would justify declaring it 'too large and fit to be rejected'. No golden rule could be laid down to say whether a particular observed value should be rejected or retained in taking the mean. To beginners, the following process based on practice will suit.

"Find the difference between arithmetic mean and each individual reading. Add up these differences, disregarding the signs and take their mean which will represent the *mean error.*

Let the values of focal length in cm of a lens as obtained by a student be (*i*) 37·2, (*ii*) 37·9, (*iii*) 38·3, (*iv*) 38·1, (*v*) 37·8, (*vi*) 38·0. The arithmetic mean is 37·9. The difference between the mean and the individual values are respectively: (*i*) −0·7, (*ii*) 0·0, (*iii*) +0·4, (*iv*) + 0·2, (*v*) −0·1, (*vi*) +0·1. When these are added up disregarding their signs, value is 1·5 and the mean value is 1·5 ÷ 6 = 0·25. The value 0·25 represents the mean error and the student may express his value as 37·9 ± 0·25 cm.

2. **Systematic Errors.** If during an experiment a factor operates in such a way as to make the observed value always higher or lower than the true value, this type of error is said to be systematic *e.g.*, instrumental errors (zero error, bench error, etc.) radiation loss or gain in calorimetry.

In the case where the source of systematic error is known, action should be taken to remove it. Thus, the zero error of a reading instrument is checked and the proper correction is applied to the reading. Error due to radiation loss is allowed to occur and then corrected for.

In some cases, the source of systematic error may not be definitely known but its existence is apparent. In such cases, the experiment is repeated under different conditions. If variation of conditions does not change the result, one may set his mind at rest that there is no systematic error.

Arithmetic mean. When a large number of observations are required, as in the measurement of the diameter of a wire, the readings should be taken all over the length and in various directions, even if most of them happen to be the same. They should all be recorded and their arithmetic mean be taken. For taking a really independent reading in the repetition of an experiment, either, if possible some other part of the scale should be used or the magnitude of the various quantities should be altered and the result be calculated in each case. The mean result must then be found. If in an experiment on simple pendulum l_1, l_2, l_3 be the three widely different lengths and t_1, t_2, t_3, the corresponding time periods then the *mean is not taken of the three lengths and the three time periods, but* l/t^2 *is calculated for each observation and the mean is taken of the nearly constant results of* l/t^2. It would be unnecessary to calculate 'g' for each observation and then get the mean value of 'g' for, in each case l/t^2 is to be multiplied by a constant $4\pi^2$.

Sometimes due to an accidental error of observation, a particular result comes out to be exceptionally too high or too low. This should be rejected or its observations, if possible, should be checked again, for it will otherwise mar the whole result. Mean cannot be taken when the different results are very much different from one another. In such cases the experiment should be performed again until the differences are reduced within the experimental error.

Combination of Errors

(*a*) **Addition and Subtraction.** If two quantities are to be added to or subtracted from each other, the error in the result is not obtained by using the fractional errors. The two errors are added together for both addition and subtraction and the result is expressed as a fraction or percentage of either the sum or the difference of the two quantities. Thus if the two measured quantities have values $x \pm \delta x$ and $y \pm \delta y$ the value of the sum will be quoted as $x+y \pm (\delta x + \delta y)$, and the value of the difference will be $x - y \pm (\delta x + \delta y)$

(*b*) **Multiplication and Division.** If two quantities x and y are multiplied together, the fractional error in the product is the sum of the two fractional errors in the x and y. Let δx, δy be the errors in x and y. Then the error in the product will be in the range :

$$(x \pm \delta x)(y \pm \delta y) - xy = \pm y\delta x \pm x\delta y \pm \delta x\delta y$$

We neglect $\delta x \delta y$ as it is small compared with $y\delta x$, $x\delta y$ etc., then the largest possible error (positive or negative) in xy will be $\pm(y\delta x + x\delta y)$ and the fractional error in xy will be $\pm\left[\left(\frac{\delta x}{x}\right) + \left(\frac{\delta y}{y}\right)\right]$ *i.e.*, the sum of the fractional errors in the x and y.

The largest value of the quotient will be $\frac{(x+\delta x)}{(y-\delta y)}$ *i.e.*, an error of $\left[\frac{(x+\delta x)}{(y-\delta y)} - \frac{x}{y}\right]$ or a fractional error of

$$\left[\frac{(x+\delta x)}{(y-\delta y)} - \frac{x}{y}\right] \div \frac{x}{y} = \frac{xy + y\delta x - xy + x\delta y}{y(y-\delta y)} \times \frac{y}{x} = \left[\frac{\delta x}{x} + \frac{\delta y}{y}\right],$$

neglecting δy in comparison with y.

The smallest value of the quotient will be $\frac{(x-\delta x)}{(y+\delta y)}$ and a similar calculation shows that the fractional error is now $-\left[\left(\frac{\delta x}{x}\right) + \left(\frac{\delta y}{y}\right)\right]$. Thus the quoted error in $\frac{x}{y}$ will be $\pm\left[\left(\frac{\delta x}{x}\right) + \left(\frac{\delta y}{y}\right)\right]$.

(*c*) Powers. It is obvious from the above that, if the same quantity x is multiplied together 'n' times (*i.e.*, x^n is obtained), the fractional error in x^n is 'n' times the fractional error in x. It is not quite so obvious that, if the nth root of x is taken, the fractional error is $\frac{1}{n}$ of the fractional error of x so we shall prove it using the binomial theorem.

$$\text{Error} = (x+\delta x)^{\frac{1}{n}} - x^{\frac{1}{n}}$$
$$= x^{\frac{1}{n}}\left[1+\frac{\delta x}{x}\right]^{\frac{1}{n}} - x^{\frac{1}{n}}$$
$$= x^{\frac{1}{n}} + x^{\frac{1}{n}}\frac{\delta x}{nx} - x^{\frac{1}{n}}$$
$$= x^{\frac{1}{n}}\frac{\delta x}{nx}$$
$$\text{Fractional error} = \frac{1}{n} \cdot \frac{\delta x}{x}.$$

(*d*) **Logarithmic Function.** If the final result contains a logarithmic function, there are two ways of dealing with the error. In the first logarithms of the mean value plus and minus the error are found, the difference taken, and this is expressed as a fraction of the log of the mean value. Secondly,

$$y = \log_e x$$
$$\delta y = \frac{\delta x}{x}.$$
$$\therefore \quad \frac{\delta y}{y} = \left(\frac{\delta x}{xy}\right) \text{ and so the error can be calculated.}$$

(*e*) **Trigonometrical Functions.** Quite often the final result depends upon the sine or some other trigonometrical function of an angle that has been measured. The fractional error wanted will be that of the function and not of the measured angle. Suppose an angle θ has been measured with an error of $\delta\theta$, and the final result includes the expression $\sin\theta$.

$$\text{error in } \sin\theta = \delta(\sin\theta) = \cos\theta\,\delta\theta$$
$$\text{fractional error} = \frac{\delta\theta}{\tan\theta}.$$

Now $\tan\theta$ can have all values from 0 to ∞ so that the fractional error can have all values from infinity to 0.

Suppose the critical angle in a medium is measured as $40^0 \pm 1^0$. What is the fractional error in the value of the refractive index ?

$$\mu = \frac{1}{\sin\theta} = \operatorname{cosec}\theta$$
$$\delta\mu = -\cot\theta\operatorname{cosec}\theta\,\delta\theta$$

$$\frac{\delta\mu}{\mu} = -\cot\theta\,\delta\theta$$

$$\cot 40^0 = 1{\cdot}19;\ \delta\theta = 1^0 = \frac{\pi}{180} = \frac{1}{60}$$

$$\frac{\delta\mu}{\mu} = \frac{1{\cdot}19}{60} = \frac{1}{50}$$

$$\mu = \operatorname{cosec} 40^0 = 1{\cdot}55 \text{ to 1 part in } 50$$

$$= 1{\cdot}55 \pm 0{:}03$$

Suppose $y = \tan x$

$$\delta y = \sec^2 x\ \delta x$$

$$\frac{\delta y}{y} = \frac{1}{\cos x\ \sin x}\,\delta x = \frac{2\delta x}{\sin 2x}.$$

This is obviously smallest when $\sin 2x$ is greatest, *i.e.*, $x = 45°$. If it is possible to choose, one chooses, angles close to 45°.

Examples on the Calculation of Errors

Example 1. The following observations were actually made during an experiment to find the value of 'g' using simple pendulum.

Length of simple pendulum = l = 100 cm

Time for 20 vibrations = 40s

Now $T = 2\pi\sqrt{\frac{l}{g}}$ when T = time period

l = length of the simple pendulum

g = Acc. due to gravity

$$\therefore\ g = 4\pi^2.\frac{l}{T^2} = 4\pi^2\frac{l}{\left(\frac{t}{20}\right)^2}$$ where t = time for 20 vibrations

or $$g = 4\pi^2 l\,.\frac{(20)^2}{t^2}.$$

Taking log of both sides

$$\log g = \log 4 + 2\log\pi + \log 1 + 2\log 20 - 2\log t$$

Differentiating, we have

$$\frac{\delta g}{g} = 0 + 0 + \frac{\delta l}{t} + 0 - \frac{2\delta t}{t}$$

Converting the negative errors into positive ones for maximum effect, we have

$$\frac{\delta g}{g} = \frac{\delta l}{l} + \frac{2\delta t}{t}$$

$$\therefore \quad \frac{\delta g}{g} = \frac{0\cdot1}{100} + \frac{2 \times 0\cdot1}{40}$$ as $\delta l = 0\cdot1\ cm$ = least count of metre scale and $\delta t = 0\cdot15$ = least count of stop watch.

$$\therefore \quad \frac{\delta g}{g} = 0\cdot001 + 0{:}0050$$
$$= 0\cdot0060.$$

$\therefore$ Maximum possible terror $= 0\cdot0060 \times 100$
$= 0\cdot60\%$

As maximum contribution to total error is $0\cdot5\%$ (*i.e.*, $0\cdot005 \times 100$) so 't' should be measured very carefully.

Example 2. The following observations were actually made during an experiment to find the radius of curvature of a concave mirror using a spherometer.

$l = 4\cdot4\ cm$

$h = 0\cdot085\ cm$

Now $R = \frac{l^2}{6h} + \frac{h}{2}$

Taking log of both sides

$$\log R = 2 \log l - \log 6 - \log h + \log h - \log 2$$

Differentiating both sides

$$\frac{\delta R}{R} = \frac{2\delta l}{l} - 0 - \frac{\delta h}{h} + \frac{\delta h}{h} - 0.$$

Converting the negative errors into positive ones for maximum effect, we have

$$\frac{\delta R}{R} = \frac{2\delta l}{l} + \frac{2\delta h}{h}$$

$$= \frac{2 \times 0\cdot1}{4\cdot4} + \frac{2 \times 0'001}{0\cdot085}$$

as $\delta l = 0\cdot1\ cm$ = Least count of metre scale

and $\delta h = 0\cdot001\ cm$ = Least count of spherometer

$$= 0\cdot045 + 0\cdot023$$

$$= 0\cdot068$$

$\therefore$ Maximum possible error $= 0\cdot068 \times 100 = 6\cdot8\%$

It is important to note that the maximum contribution to total error in the result is due to the individual error *i.e.*, 4·5% in the measurement of distance (l) between the fixed legs of the spherometer. Hence 'l' should be measured most carefully.

GRAPH

A *graph* is a line, straight or curved, showing the relation between two variable quantities (*or* their powers or functions) of which one varies as a result of the change in the other. It has, however, a much deeper significance.

Just as no amount of a wordy description of a landscape can convey the same, vivid idea to the mind as a painting or a nice photograph, so also no amount of data, however nicely recorded, can give as clearly an idea of the relationship between two variable quantities as a graph. A graph has the same utility to a scientist as a picture for a layman.

In hospitals, regular temperature charts are kept of all patients so that the doctor may at once see how the patient's temperature is rising or falling. This would not be possible if he was given figures of temperatures and time, however, nicely entered in a tabular form. Not only this, these days graphs are widely used in almost all departments. There are graphs showing the increase and decrease of revenue in various government departments. You can also have a graph how your income and expenditure varies monthly.

A graph gives not only the relation between two variable quantities, it also enable us :

1. To determine the value of a quantity not actually observed during the experiment, *e.g.*, the temperature of a patient can be known from the graph for a time when it was not actually taken.

2. To verify certain laws *e.g.*, Boyle's law, it tells us how far we have succeeded in taking our observations correctly, for if we do not obtain the required form of a graph for the given relation, we have obviously done error somewhere. The graph shows the magnitude of the error also.

3. To calibrate certain instruments and to determine their true readings, *e.g.*, ammeter, voltmeter etc.

How to Plot a Graph ? Graphs are generally plotted on a paper ruled in millimetre square. The following are few simple rules that will help a student in plotting a good graph.

1. For drawing a graph, take at least six observations extending over a wide range.

2. In case all the observations are positive, draw two thick lines at right angles to each other at the bottom and at the left hand edge of the paper to indicate the axes of reference, the horizontal line as the *abscissae* or *x-axis* and the vertical line as the *ordinate* or *y-axis* intersecting at a point O, called the *origin*. If the observations also include some negative quantities, the origin may be taken somewhere in the middle of the paper.

3. As a general rule, the quantity that is made to alter at will is called the *independent variable* and is plotted against the *x*-axis and other which varies as a result of this change is called *dependent variable* and is plotted against *y*-axis. Write clearly under the two axes the quantities which are represented by them.

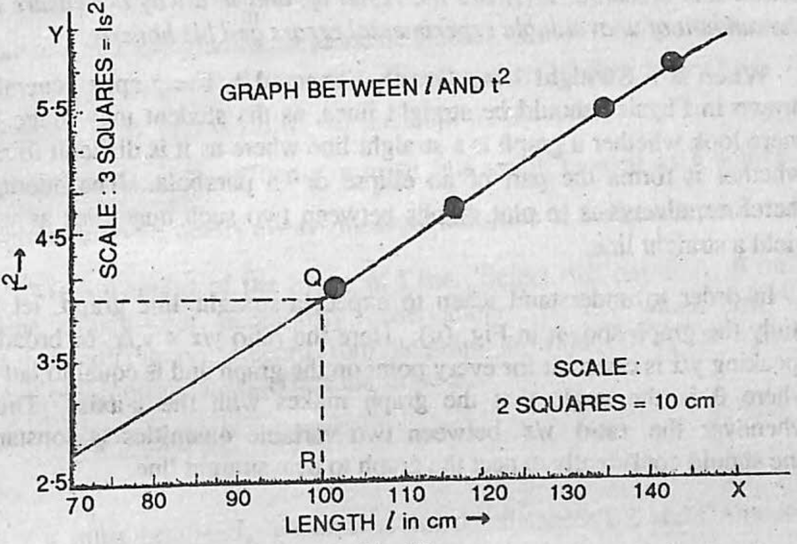


Fig. (i).

Examples. (*a*) The relation between natural numbers (*independent variable*) and their squares (*dependent variable*) can be easily represented by a graph.

(*b*) In the simple pendulum where the time period is measured for different lengths by changing the length, *length* is the independent variable and the (*time period*)^2 or t^2 the dependent variable.

(*c*) In the verification of Boyle's Law where the volume is measured for various values of pressure, *pressure* is independent variable and *volume* (or 1 /V) the dependent variable.

Sometimes for the sake of convenience, the independent variable is represented along *y*-axis and the dependent variable along *x*-axis *e.g.*, in the case of simple pendulum, it is more convenient to take 'l' along the y-axis and t or t^2 along the x-axis.

4. The scale along each axis should be chosen with a view to utilise the large part of the graph paper and at the same time retaining convenience of plotting. *The unit of length on the graph paper and the unit of the quantities to be plotted should bear, to each other, a simple ratio.* To achieve this, the round number, nearest and slightly less than the minimum value in the data should be taken near the origin and the nearest round number to the maximum value and slightly greater at the end of the required axis, *the successive value being laid along the axis in an ascending order.*

The student need not be disheartened if his points do not fall on the actual line or curve. They are the result of, and in a way a measure of, the amount of unavoidable experimental errors and his honesty.

When is a Straight Line Graph Expected ? The graphs generally drawn in Physics should be straight lines, as the student may judge by mere look whether a graph is a straight line where as it is difficult to say whether it forms the part of an ellipse or a parabola. The attempt, therefore, always is to plot graphs between two such quantities as will yield a straight line.

In order to understand when to expect a straight line graph, let us study the graph shown in Fig. (*ii*). Here the ratio $y/x = y_1/x_1$ or broadly speaking y/x is constant for every point on the graph and is equal to tan θ, where θ is the angle that the graph makes with the x-axis. Thus, whenever the ratio y/x between two variable quantities is constant, one should confidently expect the graph to be a straight line.

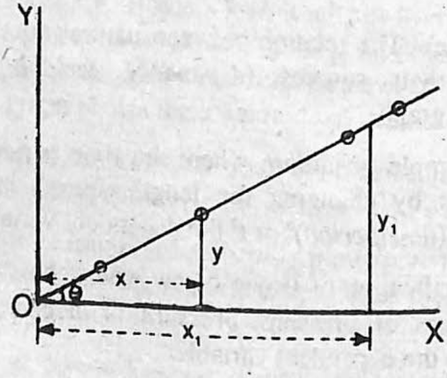


Fig. (ii).

As in Boyle's Law PV or xy is constant and not P/V or x/y, the student should put his quantities in the form of x or P and $1/y$ or $1/V$ so that $x \times 1/y$ or $P \times 1/V$ will again be a constant and the resulting graph between P and $1/V$ is a straight line. It is for this very reason that a graph between length and (time period)^2 is generally plotted in the case of a simple pendulum.

The reader will probably already know that any equation relating two unknown quantities y and x in which no powers higher than the first occur will yield a straight line when y is plotted against x. We can arrange any such linear equation in the form $\boxed{y = mx + c}$. The quantity 'm' is called the gradient or slope of the line. Lines with the same value of 'm' are all parallel (Fig. *iii*). The quantity 'c' is a measure of the distance 'OB' and is called the intercept on the Y-axis; the intercept on the x-axis is $\frac{-c}{m}$. When a straight line graph is used as a source of information we nearly always measure the slope or the intercepts or both.

Measurement of the Slope of Line. Select two points A, B on the line drawn—not necessarily observational points—which are well separated (Fig. *iv*). Record from the graph the values of y_A and x_A at (A) and of y_B and x_B (at B). Then the slope is

$$\frac{y_B - y_A}{x_B - x_A} = \frac{BC}{CA}$$

It must be clearly understood that the distances BC and CA must be

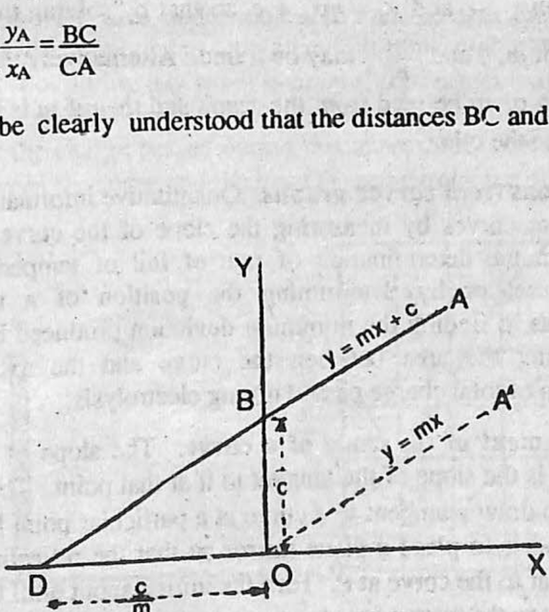


Fig. (iii).

measured in the units of the scales of the graph and *not* in centimetres or in 'squares'. They are not merely distances *e.g.*, if OY represents volts and OX amperes, the slope would be measured in ohms.

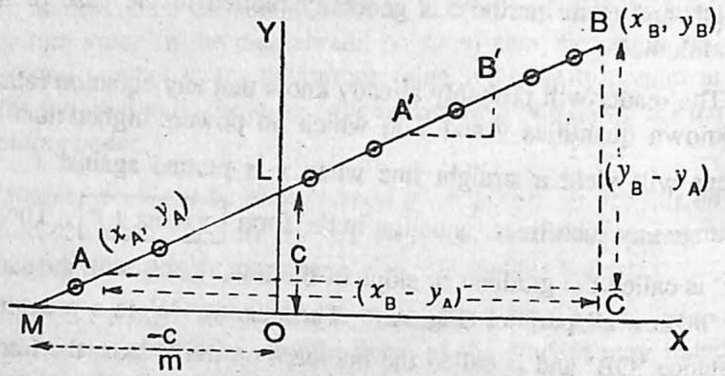


Fig. (iv).

Measurement of Intercepts. If as in Fig. (*iv*), the origin O from which the two scales are measured appears on the paper, it is easy to read off the intercepts OL and OM directly. Sometimes, however, the scale, chosen for quite sound reasons is such that the origin does not appear on the paper. In such instances two well separated points are selected as before and the values of y_A, x_A, y_B, x_B are read from the scales as before. Then $y_A = mx_A + c$ and $y_B = mx_B + c$, so that by solving these equations the values of m, c and $\frac{-c}{m}$ may be found. Alternatively the intercept on one axis can often be read from the graph and then if m is measured, we can calculate the other.

Deductions from curved graphs. Quantitative information is usually derived from curves by measuring the slope of the curve at particular points as in the determination of rate of fall of temperature from a cooling curve, or by determining the position of a maximum or minimum, as in finding the minimum deviation produced by a prism or by measuring the area between the curve and the axis, as in the computation of total charge passed during electrolysis.

Measurement of the slope of a curve. The slope of a curve at a given point is the slope of the tangent to it at that point. The problem is, therefore, to draw a tangent to a curve at a particular point P (Fig. *v*). A good method is to place a plane mirror so that the reflecting surface is perpendicular to the curve at P. Turn the mirror about until the curve and its reflection in the mirror appear as one continuous curve. The reflecting surface is then normal to the curve; so rule a line along its base with a pencil. The tangent is then the line through P at right angles to this normal and can be drawn with a set square and its slope can be measured as for any other straight line.

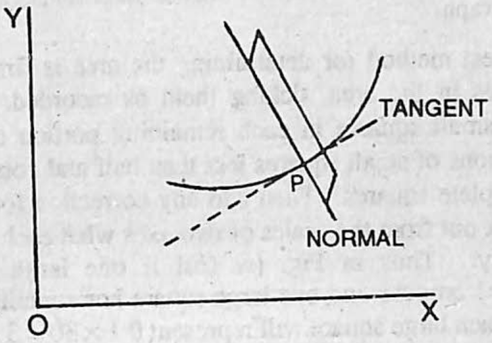


Fig. (*v*).

Measurement of the Area Under a Curve. It is sometimes necessary to measure the area lying between a curve—or a straight line—and one of the axes. For example if the current *I* during an electrolysis experiment is read at regular intervals during its performance and then *I* is plotted against *t*, the time, a curve of the type shown in Fig. *vi* (*a*) may be obtained. The area under the curve *i.e.*, the area lying between the curve and the time axis, will represent the total charge passed in coulombs. For during any small interval *t'* the current may be considered to have a constant value *I* and so the area shaded in Fig. [*vi* (*a*)] represents the charge passed during this short time. Hence the total area lying between the curve and the line OT represents the total quantity of

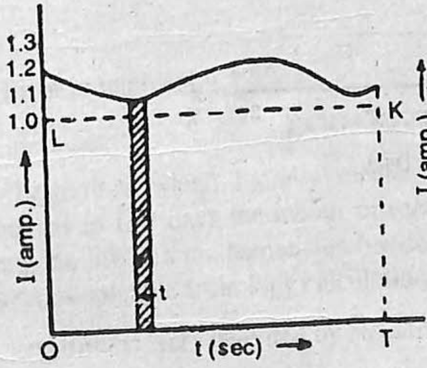


Fig. [*vi* (*a*)]

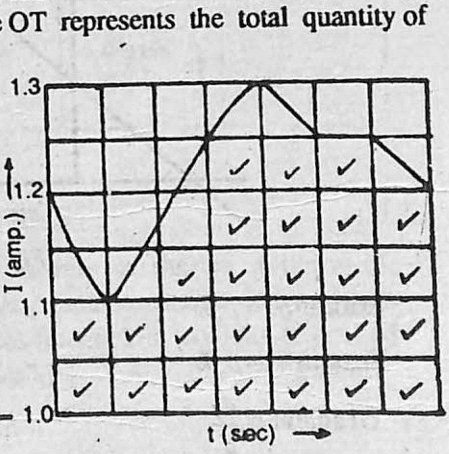


Fig. [*vi* (*b*)]

electricity which has passed through the solution. It is probable that the graph may be drawn more as in Fig. [*vi* (*b*)] with true origin not appearing *i.e.*, with the area under the line LK [Fig. *vi* (*a*)] omitted. This will enable the variations in current to be shown on a large scale. If such is the case, remember to add the area under LK to the total computed from your graph.

The easiest method for determining the area is first to count all the large squares in the area, ticking them as recorded. Then count the number of small squares in each remaining portion of a large square. Ignore fractions of small squares less than half and count all greater than half as complete squares. Then add any correction for area not shown. Finally work out from the scales of two axes what each square represents and multiply. Thus in Fig. [*vi* (*b*)] if one large square vertically represents 0·1 ampere and one large square horizontally represents 30 s the area of each large square will represent $0{\cdot}1 \times 30 = 3$ coulombs.

In all cases it is important to check that the area between the curve and the correct axis measured.

Errors in Graphical Work :

Here is a simple approach to this subject, which gives a reasonable estimate of error in a short time.

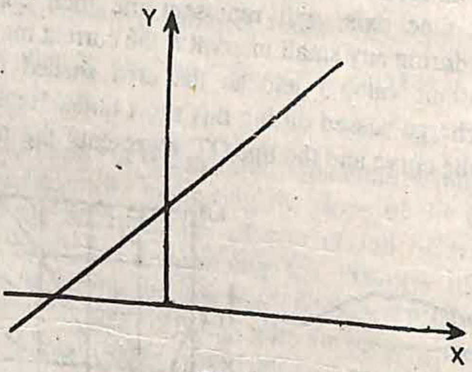


Fig. (vii).

Error in $y = p_y\%$

Error in $x = p_x\%$

Gradient $= \dfrac{d_y}{d_x}$

Error in gradient $= p_x + p_y$

Intercept = Value of x where $y = 0$

or Intercept = Value of y where $x = 0$

Error in each intercept $= p_x + p_y$.

Example : An optics experiment, to find f from $\frac{1}{u}$ and $\frac{1}{v}$

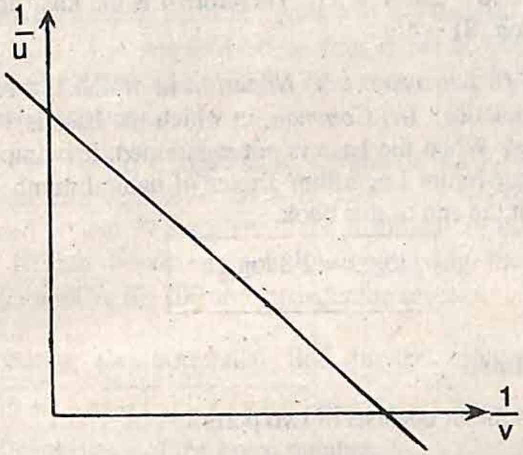


Fig. (viii).

Quantity	Value	Nature of Error	Error	%
u	20 cm	Setting Instrument	± 0·9 cm ± 0·1 cm	± 2·5%
v	20 cm	Setting Instrument	± 0·9 cm ± 0·1 cm	± 2·5%

Error in intercept = ± 5%

LOGARITHMS

[Logarithm which literally means "a rule to shorten Arithmetic", "reduces to few days the labour of many months, and so doubles, as it were, the life of a mathematician besides freeing him from the errors and digest inseparable from long calculations".] — *Laplace*

Logarithms were invented by Napier—

"My lord, I have undertaken this journey purposely to see your person, to know by what engine of wit or ingenuity you came first to think

of this most excellent help in Mathematics, viz., the logarithms."

—Briggs to Napier

Definition and Notation : If $a^x = N$, then x is called the *logarithm* of N to the base a, and is denoted by $\log_a N$ (read "log N to the base a").

[In words : The *logarithm of a number to a given base* is the *index* of the power to which the base must be raised to equal that number.]

Example : We know that $3^4 = 81$. Therefore 4 is the logarithm of 81 to the base 3, *i.e.*, $\log_3 81 = 4$.

Logarithms are of two types : (*i*) *Naperian* in which the base is *e*. They are used in practice. (*ii*) *Common*, in which the base is 10. They are commonly used. When the base is not mentioned, it is implied that the base is 10. Four-figure Logarithm Tables of natural numbers to the base 10 are given at the end of this book.

$$\boxed{\log_e x = 2{\cdot}3 \log_{10} x}$$

Common Logarithms

Logarithm of a number consists of two parts :

(1) *Characteristic* is the integral part (whole or natural number).

(2) *Mantissa* is the fractional part generally expressed in decimal form.

Note : The *mantissa* is always positive.

How to find the characteristic of a number. The characteristic depends on the magnitude of the number and is determined by the position of the decimal point. *For number greater than one, the characteristic is positive and one less than the number of digits to the left of the decimal point. For numbers smaller than one (decimal fraction), it is negative and one more than the number of zeros between the decimal part and first digit.*

Examples : Characteristic of

530800 is 5
5308 is 3
53·38 is 1
5·308 is 0
·5308 is —1
·05308 is —2
·0005308 is —4
·00005308 is —5

The negative characteristic is usually written as $\bar{1}, \bar{2}, \bar{4}, \bar{5},$ etc., and is read as bar 1, bar 2, etc.

How to find the Mantissa of a number : The value of mantissa depends on the *digits* and their *order*, and is independent of the position of the decimal point. As long as the digits and their order is the same, the mantissa is the same, whatever be the position of the decimal point.

The logarithm tables give the mantissa only. They are usually meant for number containing four digits, and if a number consists of more than four digits, it is rounded off to four digits 632562 should be taken as 6326 and 632537 as 6325. To find mantissa, tables are consulted in the following manner :

1. The first two significant figures of the number are found at the extreme left vertical column of the table wherein the number lying between 10 and 99 are given. The mantissae of the digits which are less than 10 can be determined by multiplying the figures by 10, *i.e.*, mantissae of 2, 20, 200 and so on, is the same.

2. Along the horizontal line in the topmost column the figures $\boxed{0}\boxed{1}\boxed{2}\boxed{3}\boxed{4}\boxed{5}\boxed{6}\boxed{7}\boxed{8}\boxed{9}$ are given. They correspond to the third significant figure of the given number.

3. The difference for the fourth significant digit is given further in difference column under $\boxed{1\ \ 2\ \ 3}\boxed{4\ \ 5\ \ 6}\boxed{7\ \ 8\ \ 9}$. From 10 to 19 double differences are given. If the third figure is from zero to four the upper line should be read and for the figures from 5 to 9, lower line.

Example 1. *Find the logarithm of 368·6.*

The number has 3 digits to the left of the decimal point. Hence its characteristic is 2.

To find the mantissa ignore the decimal point and look for 36 in the first vertical column and 8 in the central topmost column. Proceed from 36 along a horizontal line towards the right and from 8 vertically downwards. The two lines meet at a point where the number 5658 is written. This is the mantissa of 368. Proceed further along the horizontal line and look vertically below the figure 6 in the differences column. You will find the figure 7 there. Hence the mantissa of 3686 is 5658 + 7 = ·5665.

∴ The logarithm of 368·5 is 2·5665.

Example 2. *Find the logarithm of 368600.*

The characteristic of this number is 5 and the mantissa is the same as in example 1.

∴ Logarithm of 368600 is 5·5665.

Example 3. *Find the logarithm of ·00368633.*

The characteristic of this number is $\bar{3}$ as there are two zeros following the decimal point. We can find the mantissa of only 4 significant digits. Hence we neglect the last 2 digits (33) and find the mantissa of 3686 which is .5665.

∴ Logarithm of ·0036833 is $\bar{3}$·5665.

When the last figure of a number consisting of more than 4 significant digits is equal to or more than 5 the digit next to it is raised by one and so on till we have only 4 significant digits and if the last digit is less than 5 it is neglected as in the last example.

Imp: If we have the number 368658, the last digit is 8, therefore, we shall raise the next digit to 6 and since 6 is again more than 5, we shall raise the next digit to 7 and find the logarithm of 3687.

Antilogarithm. The number whose logarithm is *x* is called the *antilogarithm* of *x*, and is denoted by *antilog x*.

Thus since log 2=·3010, antilog ·3010 = 2.

Example 1. *Find the number whose logarithm is 1·6078.*

(*i*) The characteristic = 1. This is one less than the number of digits in the integral part of the required number, hence the number of digits in the integral part of the required number is 1+1 =2.

(*ii*) Removing the integral part 1 from the given logarithm we get ·6078. The *first two digits* from the left are 60, the *third digit* is 7 and the *fourth* is 8.

(*iii*) In the table of the antilogarithms, look in the first vertical column for ·60. In this horizontal row under the column headed by 7, we find the number 4046 at the intersection.

(*iv*) In the continuation of this horizontal row and under the mean differences column on the right headed by 8, we find the number 7 at the intersection. Adding 7 to 4046, we get 4053.

(*v*) Antilog 1·6078 = 2+·4053 = 2·4053.

Example 2. *Find the antilogarithm of $\bar{2}$·6078.*

As the characteristic is 2, there should be one zero on the right of decimal in the number. Hence antilog $\bar{2}$·6078 = ·04053.

Laws of Logarithms. From the laws of indices we obtain the following laws of logarithms :

1. $\log_a mn = \log_a m + \log_a n$

2. $\log_a m/n = \log_a m — \log_a n$

3. $\log_a m^n = n \log_a m$.

Two Important Special Cases :

(*i*) $\log_a 1 = 0$ [The logarithm of 1 to any base is zero] as $a^0 = 1$.

(*ii*) $\log_a a = 1$ [The logarithm of the base to itself is 1] as $a^1 = a$

Example 1. *Volume of a cylinder of length 3·47 cm is 1·932 cm*^{3} *Determine its radius.*

Volume $(V) = \pi r^2 l$

$$r^2 = \frac{V}{\pi l}$$

$$r = \sqrt{\frac{V}{\pi l}} = \sqrt{\frac{1·932}{3·142 \times 3·47}}$$

$$\log r = \tfrac{1}{2}(\log 1·932 — \log 3·142 — \log 3·47)$$

$$= \tfrac{1}{2}(0·2860 — 0·4972 — 0·5403)$$

$$= — \tfrac{1}{2} \times ·7515 = — ·3758 = \bar{1}·6242$$

[**Note.** The mantissa should always be in *positive* even though the logarithm comes out in negative.]

Taking antilogarithm of $\bar{1}·6242$

We get $r = ·4209$ cm

Significant Figures

Physics is the most quantitative sciences, and we must become accustomed to its insistence upon accurate measurements and precise relationships if we are to appreciate its results. Since numbers are of paramount importance in Physics, our first step will be to examine how the Physicist expresses them and just what they mean and do not mean.

Exponential notation is a convenient and widely used method for abbreviating large and small numbers. The method is based upon the fact that all numbers (in decimal form) may be expressed as a number between 1 and 10 multiplied by a power of 10. To see this we must first construct a table of powers of 10 as given below:

Powers of 10 from 10^{-10} to 10^{10}

$10^{-10} = 0{\cdot}0000000001$

$10^{-9} = 0{\cdot}000000001$

$10^{-8} = 0{\cdot}00000001$

$10^{-7} = 0{\cdot}0000001$

$10^{-6} = 0{\cdot}000001$

$10^{-5} = 0{\cdot}00001$

$10^{-4} = 0{\cdot}0001$

$10^{-3} = 0{\cdot}001$

$10^{-2} = 0{\cdot}01$

$10^{-1} = 0{\cdot}1$

$10^{0} = 1$

$10^{1} = 10$

$10^{2} = 100$

$10^{3} = 1000$

$10^{4} = 10000$

$10^{5} = 100000$

$10^{6} = 1000000$

$10^{7} = 10000000$

$10^{8} = 100000000$

$10^{9} = 1000000000$

$10^{10} = 10000000000$

Now let us look at a few examples :

$$800 = 8 \times 100 = 8 \times 10^{2}$$

$$5940 = 5{\cdot}94 \times 1000 = 5{\cdot}94 \times 10^{3}$$

$$0{\cdot}064 = 6{\cdot}4 \times 0{\cdot}01 = 6{\cdot}4 \times 10^{-2}$$

$$93{,}000{,}000 = 9{\cdot}3 \times 10{,}000{,}000 = 9{\cdot}3 \times 10^{7}$$

This method of writing large and small numbers has two great advantages. The first is that it makes numerical calculations less cumbersome and less prone to errors in many cases. An example will illustrate it

$$\frac{3800 \times 0{\cdot}0054 \times 0{\cdot}000001}{430000000 \times 73} = \frac{3{\cdot}8 \times 10^{3} \times 5{\cdot}4 \times 10^{-3} \times 10^{-6}}{4{\cdot}3 \times 10^{8} \times 7{\cdot}3 \times 10^{1}}$$

$$= \frac{3{\cdot}8 \times 5{\cdot}4}{4{\cdot}3 \times 7{\cdot}3} \times \frac{10^{3} \times 10^{-3} \times 10^{-6}}{10^{8} \times 10^{1}}$$

$$= 0{\cdot}65 \times 10^{-15}$$

$$= 6{\cdot}5 \times 10^{-16}$$

The second advantage of exponential notation is that it gives no false impressions of the degree of accuracy with which a number is known. Suppose we write the average distance '*d*' from the earth to the moon as d = 380,000 kilometres. Does this mean that d has been measured so precisely that we know it to be exactly 380,000 *km*? or even that it lies between 379,999 and 381,000 *km*? Of course not the last three Zeros merely indicate the correct location of the decimal point. If we write d as

$$d = 3{\cdot}8 \times 10^5\ km$$

then how large the number is and how accurately we know it are both clear. *The accurately known digits in a number are called* **Significant figures.** In the above case d has two significant figures 3, 8. Sometimes one or more Zeros in a number are significant figures; and it is proper to retain them when expressing the number in exponential notation, *e.g.*,

$$a = 2{\cdot}20 \times 10^8 \text{ m}$$

$$b = 6{\cdot}000 \times 10^{-4}\ sec$$

When we combine quantities arithmetically, the result has no more significant figures than the least accurately known quantity. Suppose that a man weighing 61 kg climbs into a truck weighing 16 metric tonne (not 16·000 metric tonnes). The combined weight of the man and the truck must still be considered 16 metric tonnes because all we know of the original truck weight is that it is somewhere between 15·5 and 16·5 metric tonnes. Similarly if we divide $1{\cdot}4 \times 10^5$ by $6{\cdot}70 \times 10^3$, we are not justified in writing

$$\frac{1{\cdot}4 \times 10^5}{6{\cdot}70 \times 10^3} = 20{\cdot}89552.....$$

We may properly retain only two significant figures, corresponding to the two significant figures the least accurately known number $(1{\cdot}4 \times 10^5)$ and so the correct answer is just 21.

Order of Magnitude

To estimate how big or small a given physical quantity is, we make use of the concept of *order of magnitude*. For finding out the order of magnitude of a quantity, first express it in terms of the *nearest* power of ten. The power or the exponent of ten so obtained is called the order of magnitude of the quantity. For example :

Quantity	*Expressed in nearest power of ten*	*Order of Magnitude*
7	$0{\cdot}7 \times 10^1$	1
18	$1{\cdot}8 \times 10^1$	1
83	$0{\cdot}83 \times 10^2$	2
485	$0{\cdot}485 \times 10^3$	3
1142	$1{\cdot}142 \times 10^3$	3

Basic SI Units

1. Length—metre (m)
2. Mass—kilogram (kg)
3. Time—second (s)
4. Temperature—kelvin (K)
5. Amount of Substance—mole (mol)
6. Intensity of illumination—candela (cd)
7. Current—ampere (A)

Derived Units

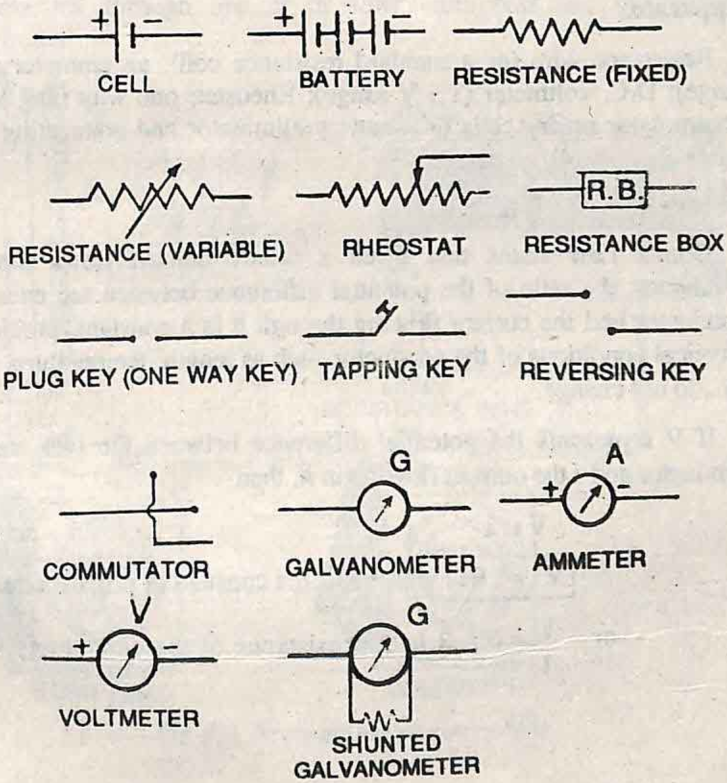
1. Energy — joule (J)
2. Force — newton (N)
3. Area — square metre (m^2)
4. Volume — cubic metre (m^3)
5. Density — kg/m^3
6. Velocity — metre per second (m/s)
7. Acceleration —metre per sec per sec (m/s^2)
8. Frequency — hertz (Hz)
9. Resistance — ohm (Ω)
10. Pressure — newton per square metre (N/m^2)
11. Potential difference — volt (V)

SECTION — A

8 Experiments are to be performed out of this section.

ELECTRICITY

Symbols used in Circuit Diagrams



EXPERIMENT 1

To study current-voltage relationship (Ohm's Law) using an ammeter and voltmeter.

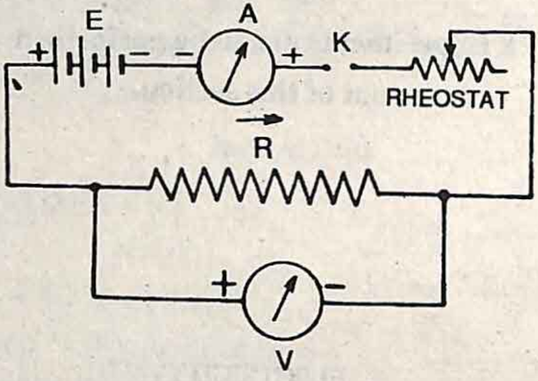


Fig. 1.1. Circuit diagram

Apparatus :

Resistance wire (or a standard resistance coil); an ammeter (1.5 A range); D.C. voltmeter (1.5 V range); Rheostat; one way plug key; An accumulator or dry cells or a battery eliminator and connecting copper wires.

Theory :

Ohm's Law states that when a steady current flows through a conductor, the ratio of the potential difference between the ends of the conductor and the current flowing through it is a constant, provided the physical conditions of the conductor such as length, temperature, density etc.,do not change.

If V represents the potential difference between the two ends of a conductor and I the current flowing in it, then

$$V \propto I$$

$$\therefore \quad \boxed{V = RI} \quad \text{where R is the constant of proportionality.}$$

$$\text{or} \quad \frac{V}{I} = R; \quad \text{R is the resistance of the conductor.}$$

When the potential difference V is measured in *volts* and the current I in *amperes*, the resistance R is measured in *ohms*.

To demonstrate current-voltage relationship (or Ohm's Law) it is to be shown that a change in potential difference at the two ends of a conductor means a corresponding charge in current in such a manner that the $\frac{\text{potential difference}}{\text{current}}$ is a constant.

A graph drawn with potential difference along X-axis and current along Y-axis should be a straight line. This line is termed as the characteristic of the conductor and will have different inclinations for different conductors.

Procedure :

1. Draw a neat circuit diagram showing the connections to be made as shown in Fig (1.1).
2. Arrange the apparatus on the working table in the laboratory and assemble the circuit connections as shown in Fig. 1.2.
3. The ammeter is connected *in series* with the resistance wire (R) or standard resistance and the voltmeter is connected *in parallel i.e.,* across it. The current must enter the ammeter and the voltmeter through their terminals marked +ve. The rheostat must be connected through one of its lower terminals and the upper terminal.

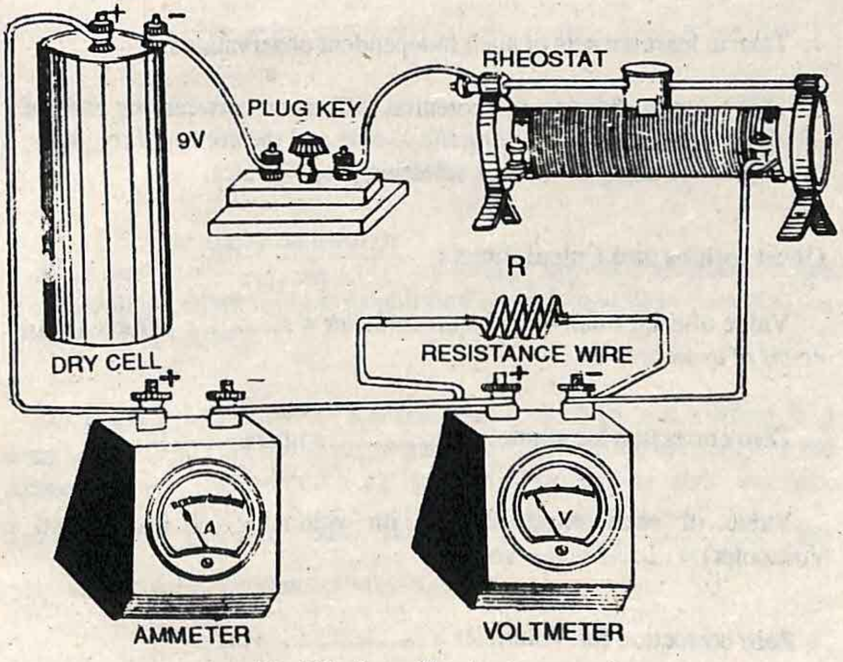


Fig. 1.2. Assembly circuit connections

4. Note the zero-errors of the ammeter and voltmeter, if any. Also before sending the current through the circuit note the *least count* of the voltmeter and the ammeter and record these in the observation tables.

5. Insert the plug key K, slide the rheostat contact strating from the left end to the right and see that the deflections in the voltmeter and Ammeter are such as to give at least ten independent sets of observations.

6. Now start the rheostat contact at one end so that a small current passes in the resistance wire or the standard resistance coil. Note down the potential difference between the ends of the experimental resistance wire *i.e.,* voltmeter reading and the current flowing in it *i.e.,* ammeter reading.

   Shift the rheostat contact slightly so that both the voltmeter and ammeter give full division readings (not in fractions). Note down these voltmeter and ammeter readings.

7. Take at least ten sets of such independent observations.

8. Plot a graph showing the potential difference between the ends of the experimental wire along the X-axis and the current through the conductor along the Y-axis selecting proper scales.

Observations and Calculations :

Value of each small division on ammeter = ... ampere (*least count of ammeter) or*

Zero correction for ammeter=............... ampere

Value of each small division on voltmeter (or least count of Voltmeter) = ... volt

Zero correction for Voltmeter = ... volt

S.No.	Voltmeter reading (Potential difference) Observed	Voltmeter reading (Potential difference) Corrected (V) in volts	Ammeter reading (Current) Observed	Ammeter reading (Current) Corrected (I) in amperes	$\frac{\text{Potential difference}}{\text{(Current)}} = \frac{V}{I}$ = a constant.
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Result :

Since the $\frac{\text{potential difference}}{\text{current}}$ comes a constant quantity, hence current-voltage relationship is established *i.e.,* voltage (V) ∝ current (I) or Ohm's Law is verified.

Since the graph between the potential difference and current is a straight line (Fig 1.3), the law has also been verified graphically or the voltage-current relationship *i. e.,* voltage ∝ current is also verified graphically. In fact the ratio $\frac{\text{potential difference}}{\text{current}}$ is the resistance of the experimental wire in ohms.

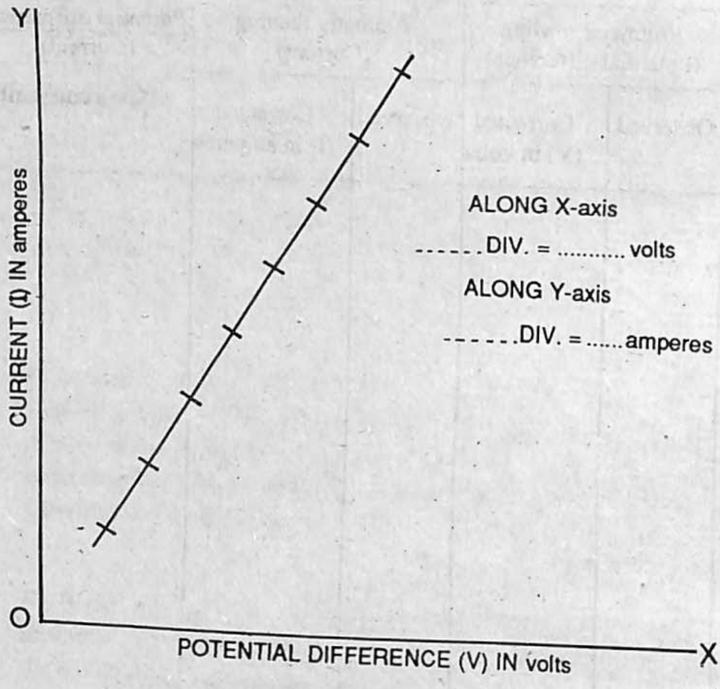


Fig. : 1.3

Precautions :

1. Clean the ends of the connecting wire with sand paper.

2. Ammeter and Voltmeter should be of proper range.

3. A low resistance rheostat should be used. Rheostat must be connected through one of its lower terminals and the upper terminal.

4. Ammeter is to be connected in series with the circuit and the voltmeter in parallel with the unknown resistance.

5. Positive of the ammeter and voltmeter should be connected to positive electrode of the battery.

6. The connections should be tight, short and straight.

7. The wires should only be connected at the terminals and not in between.

8. Get your circuit connections checked by the teacher before passing the current.

9. Do not pass current into the wire for a longer interval of time otherwise due to large heating the ratio $\frac{V}{I}$ may not remain constant.

ORAL QUESTIONS

Q. 1. *What is a current ? What is the direction of conventional current ?*

Ans. Charge in motion is called current. In the case of current through metals and other solid conductors, it is due to *flow of free electrons.* The direction of conventional current is opposite to the direction of flow of electrons.

Q. 2. *How is current measured ?*

Ans. The current is measured as charge flowing through a conductor per second.

Q. 3. *Define the different units of current.*

Ans. *e.s.u.* (Electromagnetic unit of current)

A current is said to be 1 *e.s.u.* if a charge of 1 *e.s.u.* flows through a conductor in 1 second.

e.m.u. (Electrmagnetic unit of current) :

1 *e.m.u.* of current is that current which when flowing through a circular conductor of radius 1 cm produces a field of 2π oersteds at the centre.

ampere (Practical unit) :

An ampere is defined as one coulomb of charge flowing per second through a conductor.

Q. 4. *What is a cell ?*

Ans. A cell is a device by which electric energy is generated due to chemical action taking place in it.

Q. 5. *What are different types of cells ?*

Ans. Primary cells and secondary cells.

Q. 6. *What is a Primary cell ? Give some examples.*

Ans. A primary cell is that cell in which electric energy is produced due to chemical action which is irreversible. Voltaic cell; Daniell cell; Leclanche cell; Dry cell, etc.

Q. 7. *What are the essentials of a cell ?*

Ans. A positive plate; A negative plate and electrolyte.

Q. 8. *What is Voltaic cell ?*

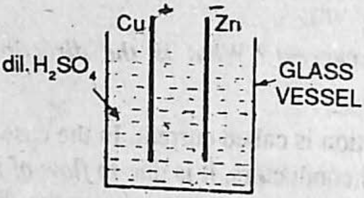


Fig . 1.4 Voltaic cell

Ans. Voltaic cell was invented by an Italian Scientist, Allexandro de Volta in 1800. It consists of two plates, one of copper, another of zinc, partly immersed in dilute sulphuric acid contained in a glass vessel (Fig. 1.4).

Q. 9. *What is Leclanche cell ?*

Ans. It consists of a glass vessel containing ammonium chloride solution and an amalgamated zinc rod. A porous pot containing a mixture of manganese dioxide and carbon powder and a carbon rod is placed in the solution. Carbon rod and zinc rod act as positive and negative electrodes respectively (Fig. 1.5).

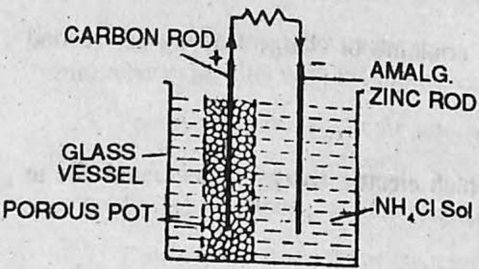


Fig. 1.5. Leclanche cell

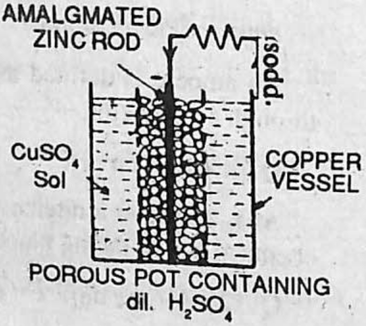


Fig. 1.6. Daniell cell

Q. 10. *What is Daniell cell ?*

Ans. It consists of a cylinderical copper vessel acting as a positive electrode and containing concentrated solution of copper sulphate acting as a depolariser. A porous pot containing dilute sulphuric acid and an amalgamated zinc rod is placed in the solution (Fig. 1.6).

Q. 11. *Why do we not get a continuous current in a Leclanche cell ?*

Ans. The depolariser MnO_2 does not oxidise hydrogen as rapidly as it is produced. Thus the current weakens after some time. It should be given some rest in order to get the full current. Thus it is used where intermittent current is required.

Q. 12. *What are the defects in Voltaic cell ?*

Ans. (i) Local Action (ii) Polarisation.

Q. 13. *What do you mean by a standard cell ? Name some.*

Ans. A standard cell is that cell which has constant E. M. F. (electro-motive force) and low temperature coefficient, *e.g.*,

Weston cadmium cell (*e.m.f.* 1.0183 volts at 20°C);

Clark standard cell (*e.m.f.* 1.4326 volts at 15°C).

Q. 14. *What do you mean by E.M.F. of a cell ?*

Ans. It is the potential difference set up across the two electrodes of a cell. It is this potential difference (P.D.) which is responsible for the motion of electricity. That is why it is called electro-motive force (E.M.F.).

Q. 15. *What is back E.M.F. ?*

Ans. In Voltaic cell, the hydrogen produced gets deposited on the copper plate. This hydrogen being electropositive produces a reverse E.M.F. in the cell which is called back E.M.F.

Q. 16. *What do you mean by internal resistance of a cell ?*

Ans. It is the resistance offered by the electrolyte between the two electrodes, when a current flows through the cell.

Q. 17. *What are the E.M.Fs. and internal resistance of Leclanche cell and Daniell cell ?*

Ans.

	E. M. F.	*Internal Resistance.*
Leclanche	1.5 Volts	3 to 4 ohms
Daniell	1.1 Volts	1 to 4 ohms

Q. 18. *Why do we get different E.M.Fs. from different cells ?*

Ans. The E.M.F. of a cell depends upon the electrodes, and electrolytes used. Since different cells have different substances as electrolytes and electrodes their, *e.m.fs.* are different.

Q. 19. *On what factors does the E.M.F. of a cell depend ?*

Ans. It depends upon the temperature and concentration of the electrolyte.

Q. 20. *Does the E.M.F. of a cell depend upon the size of the electrodes or the distance between them ?*

Ans. No; it does not depend upon the size of the electrodes or the distance between them.

Q. 21. *What is the function of a porous pot in a cell ?*

Ans. The porous pot has very minute holes which allow gases to pass through it and not solid and liquid.

Q. 22. *What is a dry cell ?*

Ans. It is a Leclanche cell in its miniature form in which the electrolyte is taken in the form of a paste. Its *e.m.f.* is 1.5. volts.

Q. 23. *What do you mean by secondary cell ?*

Ans. A secondary cell is that in which electrical energy is stored up as chemical energy by electrolysis. When current is drawn from the cell, the chemical energy is reconverted into electrical energy. The chemical reaction is reversible in this cell.

Q. 24. *Why are these cells called storage cells or accumulators ?*

Ans. These cells act as reservoirs of electricity. The current can be drawn whenever required and when they discharged, they can be charged again. As these cells store or accumulate electricity, these are called storage cells or accumulators.

Q. 25. *How many types of accumulators are there ?*

Ans. There are two types of accumulators (1) Acid or Lead accumulator, and (2) Alkali or Edison cells.

Q. 26. *Give the construction of Acid or Lead Accumulator ?*

Ans. A lead accumulator consists of a rectangular glass vessel containing two spongy lead plates made in the form of grids and packed with litharge. The electrolyte is dilute sulphuric acid of specific gravity 1.18. On charging the density increases to 1.22.

Its *e.m.f.* is 2.2 volts when fully charged and internal resistance is about 0.01 ohm. When the density falls to 1.18 and the E.M.F. becomes 1.8 volts, the cell is said to be discharged.

Q. 27. *What happens if the cell is used even after discharge ?*

Ans. If the lead accumulator is used to draw current even after it has discharged, the plates of the cells are likely to be damaged permanently by sulphating.

Q. 28. *What do you mean by short circuiting of a cell ?*

Ans. If the electrodes of a cell are connected from outside directly, it is said to be short circuiting.

Q. 29. *Can you give an idea of the high current drawn from a lead accumulator on short-circuiting ?*

Ans. As E.M.F. of the cell is 2.2 volts and its internal resistance = 0.01 ohm.

$\therefore$ Current on short circuiting = $\frac{2.2}{0.01}$ = 220 amperes which will damage the cell.

Q. 30. *What do you mean by ampere hour capacity of a storage cell ?*

Ans. It is a measure of the quantity of electricity which a cell can give. Ampere-hour capacity is numerically equal to the product of amperes and hours, *e.g.*, a cell of 20 ampere-hours capacity is capable of supplying a current of 1 ampere for 20 hours or 2 amperes for 10 hours.

Q. 31. *What is an Alkali Accumulator ?*

Ans. It consists of an aluminium vessel containing 20% solution of caustic potash in water (KOH) and 1% of lithium by hydroxide. The negative plate consists of an iron powder rigidly held in perforated capsules. Nickel peroxide held in perforated cylinders constitutes the positive plate. The *e.m.f.* of the cell is 1.35 volts. Although the *e.m.f.* of the cell is not as steady as that of an acid cell, but it is very suitable where handling of the cell is rough. The life of the cell is fairly long.

Q. 32. *What is a battery ? In what way its E.M.F. is increased ?*

Ans. Battery is a combination of cells in series. The total *e.m.f.* of the combination is the sum of the *e.m.fs.* of individual cells.

Q. 33. *What is battery eliminator ?*

Ans. It is a substitute for the usual sources of *e.m.f.* *i.e.*, dry cells; accumulators and batteries. It is essentially a rectifier of low voltage in which alternating voltage of 220 volts from the Mains is converted into a D.C. voltage of low value as desired, *e.g.*, 2V, 6V, 9V, 12V, etc.

Its advantage over other traditional sources is that no charging is required for it.

Q. 34. *What is meant by a cell in open circuit and closed circuit ?*

Ans. When no current is drawn from a cell, it is said to be in an open circuit. If the two terminals are connected to a conductor and the current is flowing, the cell is said to be in the closed circuit.

Q. 35. *Which cell is used for drawing (a) constant current, (b) large current, (c) intermittent current ?*

Ans. (*a*) Daniell, (*b*) An accumulator, (*c*) Leclanche cell.

Q. 36. *Which accumulator is used in cars ?*

Ans. Lead Accumulator.

Q. 37. *How will you distinguish between the positive and negative pole of an accumulator ?*

Ans. Generally positive poles are marked red and negative poles are marked black.

Dip wire form electrodes of the cell in acidulated water. Bubbles of hydrogen appear at the cathode.

Q. 38. *What is galvanometer ?*

Ans. A galvanometer is an instrument which is used to detect the presence of current in an electrical circuit. The zero of the scale lies at the centre so that the needle may move on both the sides according as the current flows in one direction or the other.

Q. 39. *What is a shunt ?*

Ans. It is a low resistance connected in parallel to a sensitive galvanometer.

Q. 40. *What is an ammeter ?*

Ans. An ammeter is essentially a moving coil galvanometer having a very low resistance attached to it in parallel. Its total resistance is also very low.

Q. 41. *What is a milli-ammeter ?*

Ans. It is an ammeter measuring current upto 10^{-3} ampere.

Q. 42. *What is micro meter ?*

Ans. It is an ammeter capable of measuring currents upto 10^{-6} ampere.

Q. 43. *Why do we always connect an ammeter in series in a circuit ?*

Ans. Since it has a low resistance and will not affect the current, only if it is put in series.

Q. 44. *How is it connected to the battery ?*

Ans. Its positive terminal should be towards the positive of the battery and negative towards the negative of the battery.

Q. 45. *Can this ammeter be used to measure alternating currents?*

Ans. No, it can measure only direct currents.

Q. 46. *What is a voltmeter ?*

Ans. It is a high resistance moving coil galvanometer.

Q. 47. *What is its use ?*

Ans. It is used to measure potential difference between two points directly in volts.

Q. 48. *How is it connected in the circuit ?*

Ans. It is always put in parallel to the circuit.

Q. 49. *Why is it used in parallel ?*

Ans. It is a very high resistance instrument. If it is put in series, it will consume most of the current. If used in parallel, it will not draw any appreciable current and this will not affect the main current and hence the potential difference (P.D.) between the ends remains unaltered.

Q. 50. *What is the difference between E.M.F. and P.D. ?*

Ans. E.M.F. is the potential difference across the two ends of a battery whereas P.D. is the difference of the potential between the two ends of a conductor when current flows through it. *Both are measured in volts.*

Q. 51. *What is a milli-voltmeter ?*

Ans. It is a voltmeter in which one scale division is calibrated to read 10^{-3} volt.

Q. 52. *Do the voltmeters give the exact value of potential difference ?*

Ans. No, as they have some finite resistance, some of the current passes through its coil and hence we cannot measure current value of P.D. with these.

Q. 53. *How can we measure small voltages correctly without altering these ?*

Ans. With the help of a potentiometer.

Q. 54. *What will happen if the voltmeter is connected in the circuit in series?*

Ans. As it has a very high resistance, it will decrease the current to such an extent that it may not be possible even to detect it.

Q. 55. *State Ohm's Law.*

Ans. Ohm's Law states that the current (I) passing through a conductor is directly proportional to potential difference (V) between its ends provided the physical conditions, *i.e.*, temperature, density; dimensions, etc. remain the same.

$$V \propto I$$

or $$\frac{V}{I} = R = \text{Resistance of the wire or conductor.}$$

Q. 56. *Does Ohm's Law hold good for semi-conductors ? Does it also hold good for vacuum tubes like Diodes and Triodes ?*

Ans. Ohm's Law holds good for conductors and semi-conductors but the law is not valid for the vacuum tubes like diodes and triodes and for conduction through gases.

Q. 57. *What do you mean by resistance ?*

Ans. It is the property of a conductor by virtue of which it obstructs the flow of current in it. It is measured as $R = \frac{V}{I}$ and depends upon the *dimensions* of the conductor and *nature* of its material.

Q. 58. *What is the effect of temperature on the resistance of a conductor ?*

Ans. $R_t = R_o\,[1 + \alpha t + \beta t^2]$ where R_t and R_0 are the resistances at t°C and 0°C respectively and α and β are constants.

Thus the resistance of a conductor increases with temperature.

Q. 59. *Does the resistance of all conductors increase with rise of temperature ?*

Ans. No, the resistance of electrolyte and carbon decrease with increase of temperature.

Q. 60. *What is the practical unit of resistance ?*

Ans. ohm.

Q. 61. *Define: International ampere; coulomb; volt; ohm.*

Ans. *International ampere :*

One ampere is that current which, if flowing in two straight and thin wires of infinite length placed one metre apart in vacuum, will exert on each of the wires a force of 2×10^{-7} newton per metre length of the wire.

Coulomb:

A coluomb is the quantity of electricity which passes any point in a circuit in 1 second when a steady current of 1 ampere is flowing.

Volt :

It is a unit of P.D. Two points are said to be at a potential difference of 1 volt if one joule of work is done when 1 coulomb of charge passes from one point to another.

Ohm :

One ohm is the resistance of a conductor across the ends of which a potential difference of one volt is developed when a current of one ampere passes through it.

Q. 62. *How the e.m.u. and e.s.u. unit are connected with volt and ampere?*

Ans.

$$\begin{aligned} 1 \text{ ampere} &= \tfrac{1}{10}\, \textit{e.m.u.} \text{ of current} \\ &= 3 \times 10^{9}\, \textit{e.s.u.} \text{ of current} \\ 1\, \textit{e.m.u.} \text{ of current} &= 3 \times 10^{10}\, \textit{e.s.u.} \text{ of current} \\ 1 \text{ volt} &= 10^{8}\, \textit{e.m.u.} \text{ of potential.} \\ &= \tfrac{1}{300}\, \textit{e.s.u.} \text{ of potential.} \\ 1\, \textit{e.s.u.} \text{ of potential} &= 3 \times 10^{8}\, \textit{e.m.u.} \text{ of potential.} \end{aligned}$$

Q. 63. *What do you mean by conductance ?*

Ans. The reciprocal of resistance offered by a conductor is called its conductance. Its unit is *mho*.

Q. 64. *What are conductors, semi-conductors and insulators ?*

Ans. *Conductors :*

The materials inside which large number of *free* electrons are available to conduct electricity are called conductors, *e.g.*, metals. These are materials of very low resistance.

Semi-conductors :

These are materials in which very few electrons are available to conduct electricity, *e.g.*, Silicon, Germanium, etc. Their resistances lie between the resistance of conductors and insulators.

Insulators :

These are materials in which no free electrons are available to conduct electricity, *e.g.*, mica,dry wood, rubber, etc. Their resistance is very high.

Q. 65. *Why are connecting wires made thick and covered with silk or cotton?*

Ans. The connecting wires are all copper wires. These are made thick so that they offer negligible resistance. They are covered with silk or cotton to insulate them.

Q. 66. *What is the law of resistances in series ?*

Ans. In series the combined resistance is equal to the sum of the individual resistances

$$R = r_1 + r_2 + r_3 + \dots\dots\dots$$

Q. 67. *What is the law of resistances in parallel ?*

Ans. In parallel, the reciprocal of the combined resistance is equal to the sum of the reciprocals of individual resistances.

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \dots\dots\dots$$

Q. 68. *What is a resistance box and how are the resistances arranged in it ?*

Ans. A resistance box consists of one or more standard resistances of different values connected in series and mounted in a box. The upper ends of the resistance wires are joined to brass studs fixed in such a way that they can be joined together by putting plugs in between them.

Q. 69. *What is meant by infinity plug ?*

Ans. Infinity plug is that which when taken out introduces an infinite resistance. There is no resistance wire below it but there is only air gap thus making the resistance infinite.

Q. 70. *What is the material of the wire used for making these standard resistances ?*

Ans. The resistance coils are made of manganin or constantan wires doubly insulated by means of silk threads.

Q. 71. *What is the composition of manganin or constantan ?*

Ans. The composition of manganin is copper 84%; nickel 4% and manganese 12%. Constantan consists of copper 60% and nickel 40%.

Q. 72. *Why is the resistance wire doubled on itself before winding on the bobbin?*

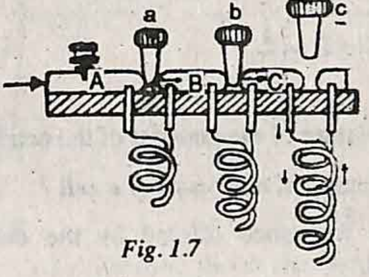


Fig. 1.7

Ans. To eliminate the inductive effect as the current flows in opposite directions in two halves of the doubly wound wire. Such type of coils are called *non-inductive coils*. (Fig. 1.7).

Q. 73. *What is a Rheostat and what is its use ?*

Ans. A rheostat is a device used to introduce available resistance in a circuit. It is used to control the flow of electric current.

Q. 74. *What is the material of the wire used in a Rheostat and why ?*

Ans. Generally we use manganin or constantan wire because their change of resistance per degree rise of temperature is very small.

Q. 75. *What is the material of the tube on which resistance wire is wound ?*

Ans. The tube is made of some non-conducting material like enamelled iron, slate or porcelain, etc.

Q. 76. *What is 1 mega-ohm (2) micro ohm ?*

Ans. 1 mega-ohm= 10^6 ohms

1 micro-ohm=10^{-6} ohm

Q. 77. *What is a plug key and what is its resistance ?*

Ans. It is a key which is used in the electrical circuit when a constant current is desired for a long time. It consists of two thick brass blocks having an air gap in between and are fixed on an ebonite base. A metal plug may be inserted in the air gap when circuit is to be closed and may be taken out of the gap when the circuit is to be broken.

When the plug is inserted the resistance of the key is negligibly small and when the plug is removed, the resistance is infinite.

Q. 78. *On what factors does the resistance of a conductor depend ?*

Ans. (1) Length of the conductor (l)

$$R \propto l$$

(2) Area of cross-section (a)

$$R \propto \frac{1}{a}$$

(3) Nature of the material of the conductor.

Q. 79. *What is internal resistance of a cell ?*

Ans. It is the resistance offered by the electrolyte between the electrodes of a cell.

Q. 80. *Is the internal resistance of all the cells same ?*

Ans. No; it is different for different cells.

Q. 81. *On what factors does the internal resistance of a cell depend ?*

Ans. (1) Distance between the plates.

(2) Area of the plates immersed in the electrolyte. If area increases, the internal resistance decreases.

(3) The nature of the electrolyte.

(4) The nature of the electrodes.

Q. 82. *Define specific resistance ?*

Ans. It is the resistance offered by a cm cube, the current flowing normally to the face.

Q. 83. *What is the unit of specific resistance ?*

Ans. ohm-cm.

Q. 84. *What is conductivity ?*

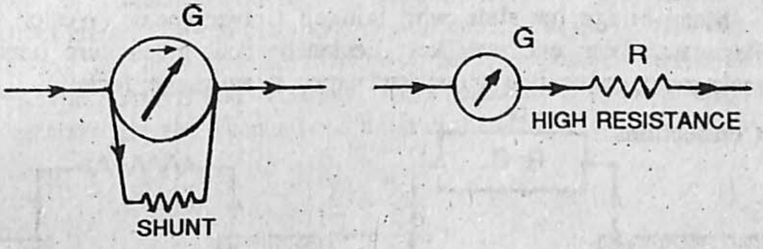
Ans. The reciprocal of specific resistance is called conductivity.

Q. 85. *Can you convert a galvanometer into a voltmeter and an ammeter ? If so, how ?*

Ans. Yes, a galvanometer can be converted into a voltmeter and an ammeter ?

A galvanometer can be converted into an ammeter by putting a wire of low resistance (shunt) parallel to it [Fig. 1.8 (*a*)].

A galvanometer can be converted a voltmeter by connecting a high resistance in series with it [Fig 1.8 (*b*)].



(a) Ammeter *(b) Voltmeter*

Fig. 1.8. Conversion of a galvanometer into an ammeter and a voltmeter

□□

EXPERIMENT 2

To use a Wheatstone's bridge (metre-bridge) for finding an unknown resistance.

Apparatus :

Metre-bridge (or slide wire bridge); Galvanometer (Weston type); Resistance box; one way key; Leclanche cell, given wire (unknown resistance); connecting wires; sand paper; screw gauge; Jockey.

Connections :

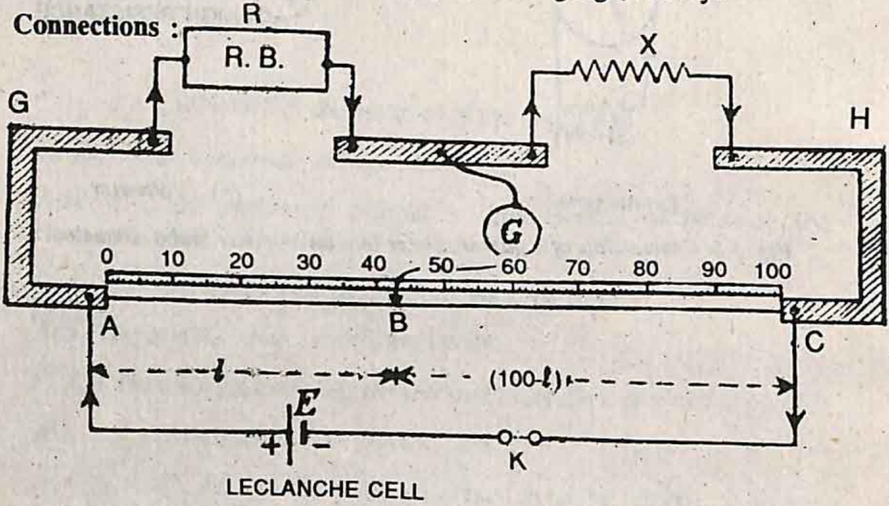


Fig. 2.1. Metre-bridge circuit diagram.

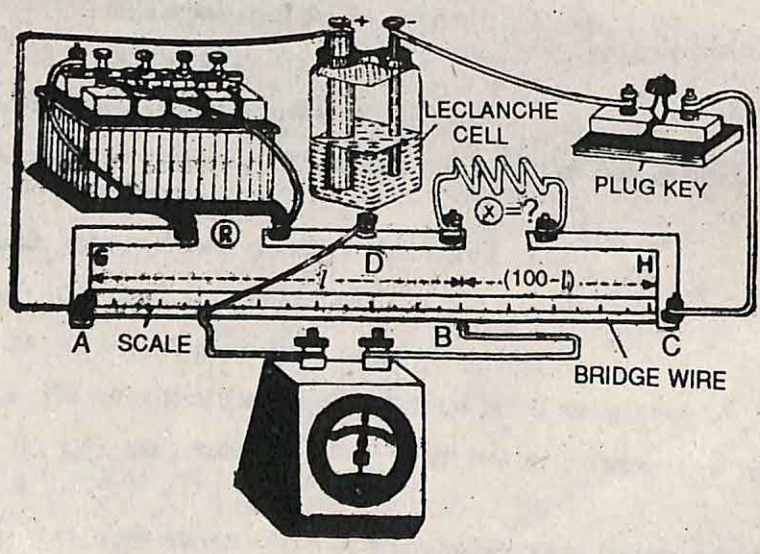


Fig 2.2 : Assembly diagram of the metre bridge.

Theory :

Wheatstone bridge :

It consists of four resistances P, Q, R and S arranged as shown in Fig. 2.3, so as to form a closed quadrilateral ABCD. One pair of opposite junctions is connected through a cell and the other pair of opposite junctions is connected through a galvanometer. If the values of resistances are so adjusted that there is no deflection in the galvanometer by pressing the key K, then there will be no potential difference between the points B and D. Hence the wheatstone bridge is said to be balanced and under the balanced condition of the bridge

$$\boxed{\frac{P}{Q}=\frac{R}{S}}$$

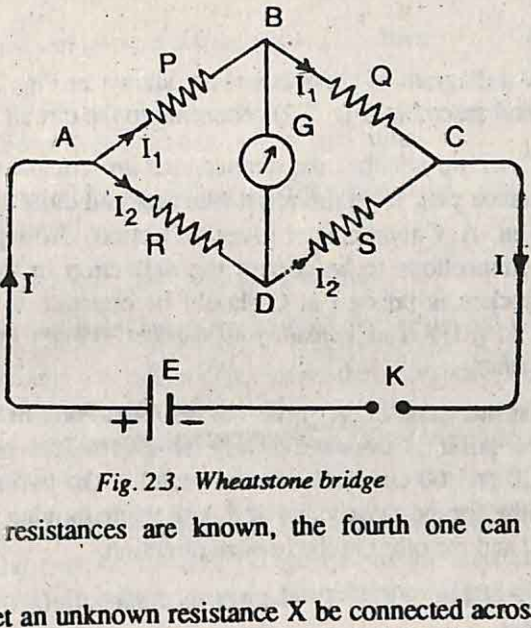


Fig. 2.3. Wheatstone bridge

If the three resistances are known, the fourth one can be easily calculated.

In Fig. 2.1, let an unknown resistance X be connected across the right hand gap and a resistance box (R.B.) across the left hand gap of the metre bridge. A Leclanche cell (E) and a galvanometer (G) are also connected across AB and BD, respectively. Let the balance point be obtained at the position B on the wire. In the balanced condition from the Wheatstone bridge principle, we have

$\frac{P}{Q}=\frac{R}{X}$ where P and Q are the resistances of the portions AB and BC of the wire respectively.

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If the wire of the metre bridge is of uniform area cross – section, then the resistance of AB $\propto$ length AB

and resistance of BC $\propto$ length BC

If AB = l then BC = 100 — l because AC = 100 cm

= 1 metre

Hence

$$\frac{P}{Q} = \frac{R}{X} = \frac{l}{(100 - l)}$$

or

$$\boxed{X = R\,\frac{(100 - l)}{l}}$$

Since R and l are known hence unknown resistance X of the given wire can be easily determined.

Procedure :

1. Draw a diagram of connections as shown in Fig. 2.1. Arrange the apparatus and assemble (Fig. 2.2) according to the circuit diagram.

2. To check up whether the connections are correct or not, take out some resistance plug from the resistance box and close the key K. Press the jockey at A. Galvanometer gives deflection. Now press the jockey at C. For connections to be correct the deflection in the galvanometer when the jockey is pressed at C should be opposite to that when it is pressed at A. *If is not so, consult your teacher, remove the fault and then proceed further.*

3. Adjust the value of 'R' from the resistance box in such a way that the balance point is obtained nearly at the middle of the wire AC (between 30 and 60 cm mark on the scale). Take two readings for the balance point for the same value of R, one while moving the jockey from left to right and the other in the reverse direction.

4. Note R, l and (100 — l) where 'l' is the length (AB) of the wire for the null point.

5. Repeat the experiment four times with *different* values of 'R'.

Observations and Calculations :

S. No.	Resistance (R) from R. B. (ohm)	Position of the balance point (B) cm	Length (AB) = l (cm)	Length (BC) = $(100 - l)$	Unknown Resistance $X = R.\frac{(100 - l)}{l}$ (ohm)
1.					
2.					
3.					
4.					

Mean X = ... ohm

Result :

The value of the unknown resistance X = ... ohms

Precautions :

1. All connections should be neat, clean and tight.

2. As far as possible the balance point should be confined to the middle region of the wire.

3. In the resistance box, the plugs must be tight.

4. The jockey should not touch the wire when it is moved to and fro.

5. After obtaining the balance position, the resistance box and the unknown resistance should be interchanged and the no deflection position should be obtained again. This way the index error becomes ineffective.

6. The key in the cell circuit should be closed first and only then the jockey should be pressed so that the galvanometer does not show a deflection because of induced *e.m.f.*, but when breaking the current, reverse should be done.

7. Keep the key of the battery closed only when the reading is being taken and open it immediately after that to minimise the error due to change of resistance by heating.

8. While finding out balance point, the jockey should not be pressed too hard otherwise the uniformity of the wire will be affected.

Sources of Error :

1. The metre bridge wire may not be of uniform area of cross section throughout its length.

2. The thick copper strips at the two ends of the wire offer some resistances. These resistances at the ends are called End resistances; the errors are called End errors and the corresponding corrections are called End corrections.

3. As current passes through the wire, it gets heated and its resistance changed.

ORAL QUESTIONS

(See Expt. No. 3)

EXPERIMENT 3

To verify the laws of resistances in series and in parallel using a metre-bridge (or slide wire bridge).

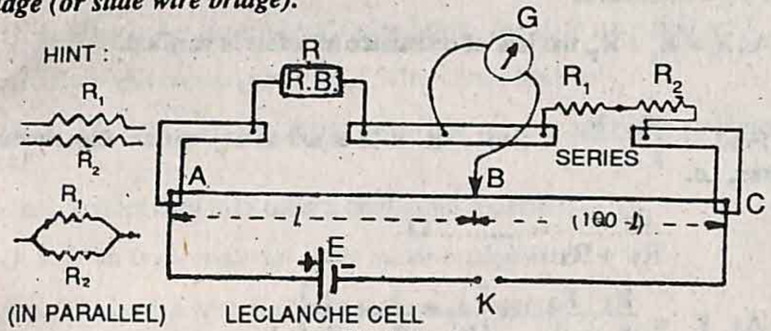


Fig. 3.1

Procedure :

Proceed same way as in Expt. 2. Find R_1.

Remove first resistance R_1 and put second resistance R_2.

Find R_2.

Now put R_1 and R_2 in series and Find R_s.

Now put R_1 and R_2 in parallel and Find R_p.

Observations and Calculations :

Resistance	S. No.	Resistance (R) from the R.B. (ohm)	Position of the balance point (B)	Length AB = l (cm)	Length (BC) = $(100 - l)$ cm.	Unknown resistance $= \frac{R(100 - l)}{l}$ (ohms)
R_1	1					
	2					
	3					Mean R_1 = ...
R_2	1					
	2					
	3					Mean R_2 = ...
R_1 and R_2 in Series	1					
	2					
	3					Mean R_s = ...
R_1 and R_2 in Parallel	1					
	2					
	3					Mean R_p = ...

Verification :

Find $R_1 + R_2$. See that it is equal to R_s within experimental error *i.e.*, $R_1 + R_2 =$ .... Ω

As $R_s = R_1 + R_2$; the law of resistance in series is verified.

Find $\frac{R_1 R_2}{R_1 + R_2}$. See that it is equal to R_p within experimental errors, i.e.

$$\frac{R_1 R_2}{R_1 + R_2} = \text{..........}\ \Omega$$

As $R_p = \frac{R_1 R_2}{R_1 + R_2}$ or $\left[\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}\right]$,

the law of resistances in parallel is verified.

Precautions : Same as in Expt. 2.

Sources of Error : Same as in Expt. 2.

ORAL QUESTIONS

Q. 1. *What is Wheatstone bridge principle ?*

Ans. A network of four resistances P, Q, R and S joined in such a way as to form the four sides of a quadrilateral ABCD (Fig. 2.3), is known as Wheatstone bridge. The opposite corners A and C are connected through the battery while B and D are connected through the galvanometer. The resistances are so adjusted that galvanometer shows no deflection.

In this position:

$\boxed{\frac{P}{Q} = \frac{R}{S}}$ which is Wheatstone bridge principle.

Q. 2. *Why is it so called ?*

Ans. It is so called because it was discovered by Sir Charles Wheatstone. It is called a bridge because the galvanometer circuit acts like a bridge which joins the two points having the same potential.

Q. 3. *What is a metre-bridge (or slide wire bridge) ?*

Ans. It is an instrument used to determine the resistance and consists of a wire one metre long stretched on a wooden board. Two gaps are provided to introduce suitable resistances. The galvanometer arm bridges two equal potentials at the null point, which is obtained by sliding the jockey over the wire. Hence, it is called slide wire bridge (Fig. 2.1).

Q. 4. *What is the principle of metre-bridge (or slide wire bridge) ?*

Ans. It works on the principle of Wheatstone bridge.

Q. 5. *Why the copper strips fitted on the metre-bridge are made thick?*

Ans. So that they may offer a negligible resistance.

Q. 6. *What is the material of the metre-bridge wire ?*

Ans. The bridge wire is of manganin or constantan.

Q. 7. *What type of bridge wire should be ?*

Ans. It should have uniform area of cross-section; high resistance and low temperature coefficient.

Q. 8. *Why should we get the balance point preferably at the middle of the wire ?*

Ans. To get the maximum accuracy. In this case the ratio arms are nearly equal and the end resistances of copper strips also produce the least effect. Hence the bridge is most sensitive.

Q. 9. *Why should the jockey be not pressed too hard ?*

Ans. Because by pressing hard, the wire will become flat at that point and its area of cross-section will no longer be uniform and hence the resistance of the wire will not be proportional to its length.

Q. 10. *Can we find very high or very low resistances accurately with a metre-bridge ?*

Ans. No; we cannot find very high or very low resistance accurately.

For maximum sensitivity the resistances of all the four arms of the bridge should be of the same order. Consequently, the magnitude of the unknown resistance to be determined should be approx., half of the resistance of the bridge wire. Hence an ordinary metre-bridge is not suitable for measuring high and very low resistances. For the measurement of low resistances, another difficulty arises owing to the resistances of the strips and connecting wires becoming comparable to the unknown low resistance and cannot be neglected.

Q. 11. *What are End resistances and End corrections in a metre-bridge ?*

Ans. We have assumed that in a metre-bridge the resistance of the copper strip and the soldering at the ends of the bridge wire are negligible, but actually they are not so small as to be neglected. Moreover the bridge wire may not be exactly one metre long and the scale may not be exactly placed with respect to the wire either because the wire is slightly longer or shorter or because of the difficulty of making the connections between the ends of the wire and the strips exactly at the ends of the scale. The effect of all these factors is to introduce some unknown resistance at the two ends of the wire. These resistances at the two ends of the wire are called End resistances, the errors are called End errors and the corresponding corrections are called End corrections.

Q. 12. *How do we overcome End resistances ?*

Ans. In a modified and improved form of metre-bridge called Cary-Foster Bridge.

Q. 13. *What is a null point ?*

Ans. When there is no deflection in the galvanometer, the point on the wire below the jockey is called null point.

Q. 14. *Will the null point be affected if we use :*
(a) Hollow wire (b) German silver wire.

Ans. No; it will not be affected in both the cases.

Q. 15. *Is the bridge method superior to Ohm's Law method and why ?*

Ans. Yes; because it is a null method.

Q. 16. *Define specific resistance.*

Ans. It is the resistance offered by a conductor whose length is 1 cm and area of cross-section 1 cm^2; the current flowing normally to the face.

Q. 17. *What is the unit of specific resistance ?*

Ans. Ohm-cm. In S.I. Units it is ohm-m.

Q. 18. *Has temperature any effect on the specific resistance ?*

Ans. Yes; the specific resistance of pure metals decreases with temperature.

Q. 19. *Why do we press the battery key before pressing jockey on the wire ?*

Ans. To eliminate the inductive effect.

Q. 20. *If a wire of certain length is stretched to twice its length, how will its specific resistance change ?*

Ans. Specific resistance will remain the same as it depends on the material of the wire.

Q. 21. *Why we take a large number of readings to measure diameter of the wire ?*

Ans. As the square of the diameter is involved in the formula, a small error in its measurements will introduce a large error.

Q. 22. *What will happen if no resistance is used in the ratio of P and Q?*

Ans. The cell may get damaged due to short circuiting.

Q. 23. *Why do you use a shunt with the galvanometer while trying for a balance point ?*

Ans. To bring the deflection in the galvanometer in scale.

Q. 24. *Will there be any difference in the situation, if the positions of the cell and the galvanometer are interchanged under the balanced conditions ?*

Ans. No; the relation $\frac{P}{Q}=\frac{R}{S}$ still holds good.

Q. 25. *When is Wheatstone bridge most sensitive ?*

Ans. The bridge is most sensitive when the four resistances are of the same order of magnitude. Hence the necessity of obtaining balance point in the middle.

(See more Questions in Expt. 1).

□ □

EXPERIMENT 4

To determine the specific resistance of the material of a wire using a metre-bridge.

Apparatus :

Metre-bridge (or slide wire bridge); Galvanometer (Weston type); Resistance box; one way key; Leclanche cell; given wire (unknown resistance); connecting wires; sandpaper; screw gauge, jockey.

Connections :

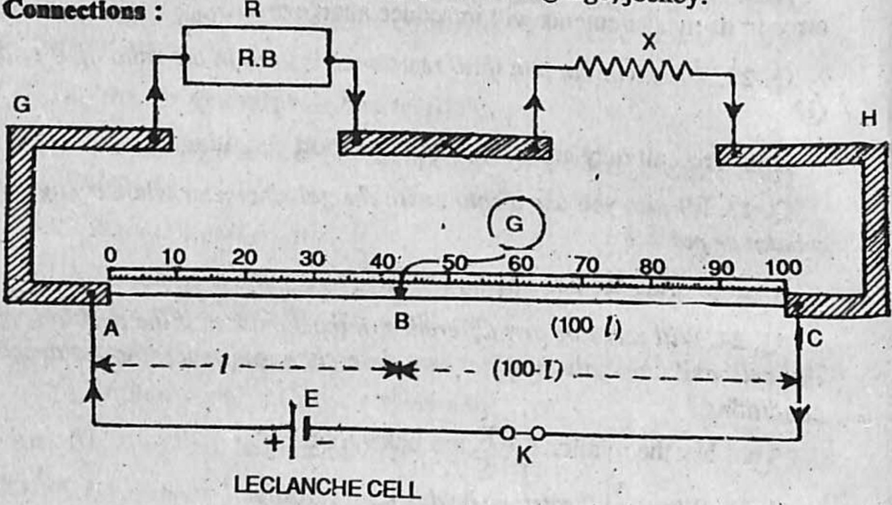


Fig. 4.1. Metre-bridge circuit diagram.

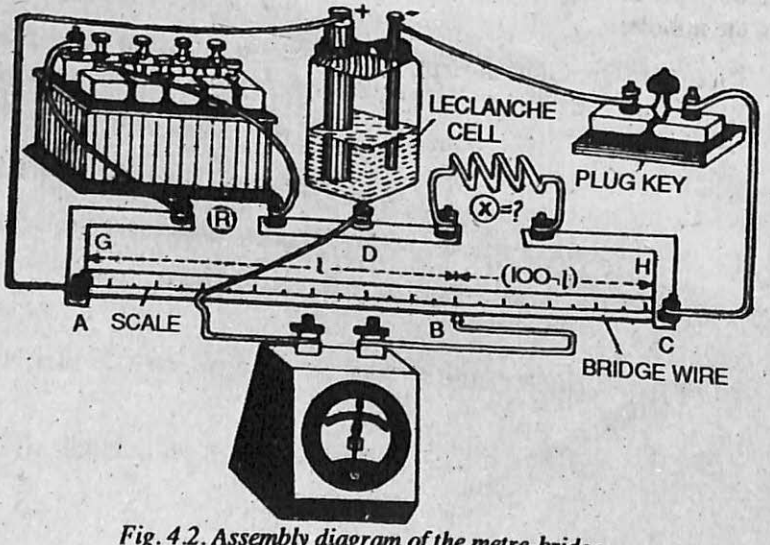


Fig. 4.2. Assembly diagram of the metre-bridge.

Theory :

Wheatstone bridge :

It consists of four resistances P, Q, R and S arranged as shown in Fig. 4.3, so as to form a closed quadrilateral ABCD. One pair of opposite junctions is connected through a cell and the other pair of opposite junctions connected through a galvanometer. If the values of resistances are so adjusted that there is no deflection in the galvanometer by pressing the key K, then there will be no potential difference between the points B and D. Hence the wheatstone bridge is said to be balanced and under the balanced condition of the bridge :

$$\boxed{\frac{P}{Q}=\frac{R}{S}}$$

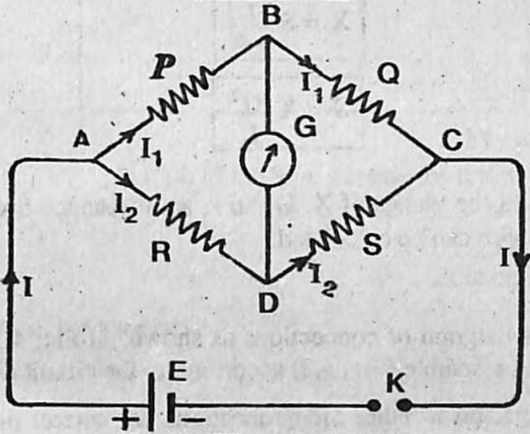


Fig. 4.3. Wheatstone bridge

If the three resistances are known, the fourth one can be easily calculated.

In Fig. 4.1, let an unknown resistance X be connected across the right hand gap and a resistance box (R.B.) across the left hand gap of the metre bridge. A Leclanche cell (E) and a galvanometer (G) are also connected across AB and BD, respectively. Let the balance point be obtained at the position B on the wire. In the balanced condition from the Wheatstone bridge principle, we have

$\frac{P}{Q}=\frac{R}{X}$ where P and Q are the resistances of the portions AB and BC of the wire respectively.

If the wire of the metre-bridge is of uniform area cross-section, then the resistance of AB $\propto$ length AB

and resistance of BC $\propto$ length BC

If AB = l then BC = 100 — l because AC = 100 cm = 1 metre

Hence $$\frac{P}{Q} = \frac{R}{X} = \frac{l}{(100 - l)}$$

or $$\boxed{X = R\,\frac{(100 - l)}{l}}$$

Since R and l are known hence unknown resistance X of the given wire can be easily determined.

Let 'S' be the specific resistance of the given wire; 'L' be its length and 'r' be its radius, then

$$\boxed{X = S\,\frac{L}{\pi r^2}}$$

or $$\boxed{S = X\,\frac{\pi r^2}{L}}$$

Substituting the vlaues of X, L and r, sp. resistance S of the material of the given wire can be calculated.

Procedure :

1. Draw a diagram of connections as shown in Fig. 4.1. Arrange the apparatus and assemble (Fig. 4.2) according to the circuit diagram.

2. To check up whether the connections are correct or not, take out some resistance plug from the resistance box and close the key K. Press the jockey at A. Galvanometer gives deflection. Now press the jockey at C. For connections to be correct the deflection in the galvanometer when the jockey is pressed at C should be opposite to that when it is pressed at A. If it is not so, consult your teacher, remove the fault and then proceed further.

3. Adjust the value of 'R' from the resistance box in such a way that the balance point is obtained nearly at the middle of the wire AC (between 30 and 60 cm mark on the scale). Take two readings for the balance point for the same value of R, one while moving the jockey from left to right and the other in the reverse direction.

4. Note R, l and (100— l) where 'l' is the length (AB) of the wire for the null point.

5. Repeat the experiment four times with different values of 'R'.

6. Cut the resistance wire X *at the points at which it just comes out of the terminals* and find its length (L) correctly with a metre rod.

7. Find the radius (r) of the wire at four or five places with a screw gauge.

Observations and Calculations :

S. No.	Resistance (R) from R. B. (ohm)	Position of the balance point (B) cm	Length (AB) = l (cm)	Length (BC) = $(100 - l)$	Unknown Resistance $X = R.\frac{(100 - l)}{l}$ (ohm)
1.					
2.					
3.					
4.					

Mean X = ... ohm

Length of the wire outside the terminals = L = ...cm

Least count of the Screw Gauge =.... mm

Zero error =.... mm

Zero correction =.... mm

Diameter of the wire :

(1) ....mm (2) ....mm (3) ....mm (4) ....mm

Mean observed diameter = ... mm

Corrected diameter = d =............mm

Radius $r = \frac{d}{2}$ = ... mm

= ....cm

= .... m

Specific Resistance

$$S = X.\frac{\pi r^2}{l}$$

= ......ohm-cm = ...ohm-m

Actual value from table

=........ohm-cm =.........ohm-m

Difference = ... ohm-cm =..... ohm-m

$$\% \text{ error} = \frac{\text{difference}}{\text{actual value}} \times 100\% = \ldots\ldots\ldots\ldots\%$$

Result :

(*a*) The value of the unknown resistance X = ... ohms

(*b*) The sp. resistance of a given wire = ... ohm-cm =.... ohm-m

Precautions :

1. All connections should be neat, clean and tight.

2. As far as possible the balance point should be confined to the middle region of the wire.

3. In the resistance box, the plugs must be tight.

4. The jockey should not touch the wire when it is moved to and fro.

5. After obtaining the balance position, the resistance box and the unknown resistance should be interchanged and the no deflection position should be obtained again. This way the index error becomes ineffective.

6. Measure only that length of the experimental wire which is outside the binding terminals.

7. The key in the cell circuit should be closed first and only then the jockey should be pressed so that the galvanometer does not show a deflection because of induced *e.m.f.*, but when breaking the current, reverse should be done.

8. Keep the key of the battery closed only when the reading is being taken and open it immediately after that to minimise the error due to change of resistance by heating.

9. While finding out balance point, the jockey should not be pressed too hard otherwise the uniformity of the wire will be affected.

Sources of Error :

1. The metre bridge wire may not be of uniform area of cross-section throughout its length.

2. The thick copper strips at the two ends of the wire offer some resistances. These resistances at the ends are called End resistances; the errors are called End errors and the corresponding corrections are called End corrections.

3 As current passes through the wire, it gets heated and its resistance changed.

ORAL QUESTIONS

(See Expt. No. 3)

EXPERIMENT 5

To find the resistance of a given wire using Post Office Box and hence to determine the specific resistance of the material of the wire.

Apparatus :

A post office box, moving coil galvanometer, a cell, a screw gauge, connecting wires, sand paper, a wire about one metre long of the material whose specific resistance is to be determined, a metre rod and a razor blade.

Theory :

Post Office Box :

A post office box is a compact form of the wheatstone bridge. As shown in Fig 5.1, it consists of two arms AB and BC called the *ratio arms* (P, Q), each carrying three resistance coils of 10, 100 and 1000 ohms. The third *rheostat arm* AD is an ordinary resistance box consisting of a series of coils of resistances 1 to 5,000 ohms. The unknown resistance X to be calculated is connected in the fourth arm CD of the bridge.

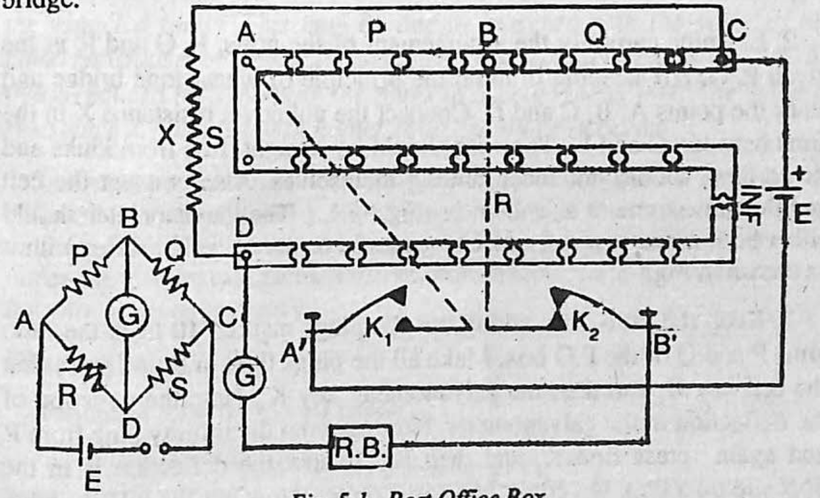


Fig. 5.1. Post Office Box

A Leclanche cell is connected between A and C through a spring key K, which when pressed makes contact with A internally as shown by dotted line. The galvanometer G is connected between B and D through another spring key K_2.

For smaller resistance X, the ratio 1, 10 and 100 by taking out Q = 10 and P = 10, 100 and 1,000 should be used and for the resistance X of medium value ratio 1, .01 and 001 by taking P = 10 and Q = 10, 100 and

1000 should be used. When X >100 ohms or < 0.01 ohm, its value cannot be determined. The position of the cell and galvanometer can be interchanged. Usually the resistance of the galvanometer is larger than that of the cell and for greater sensitiveness, galvanometer is connected to the junction of two large resistances and the junction of two smaller resistances, the cell is connected with the other two junctions. With these connections, the current in the circuit and hence in galvanometer is larger for any unbalanced position.

If K = specific resistance of the wire.

X = Resistance of the wire.

r = radius of the wire.

and l = length of the wire.

then $K = X \frac{\pi r^2}{l}$ ohms cm^{-3} .

Procedure :

1. Draw a circuit diagram showing the scheme of connections as in Fig. 5.1.

2. Examine carefully the arrangement of the arms, P, Q and R in the given P. O. box keeping in mind the principle of wheatstone bridge and mark the points A, B, C and D. Connect the unknown resistance X in the arms between C and D. The wire should be straight, free from kinks and its portions should not touch among themselves. Also connect the cell and the galvanometer as shown in Fig. 5.1. The galvanometer should either be shunted or a resistance box should be connected in series with it as shown in Fig. 5.1.

3. Keep the ratio 1 by taking out the plugs marked 10 from the ratio arms P and Q of the P.O box. Make all the plugs tight in R and press first the cell key K_1 and then the galvanometer key K_2. Note the direction of the deflection in the galvanometer. Now take out the infinity plug from R and again press first K_1 and then K_2. If now the deflection is in the opposite direction, the corrections are correct. Now put the infinity plug. Adjust the resistance from the arm R so that with a certain resistance, the deflection is towards right/left and with *one ohm* more or less, the deflection is to the opposite side left/right. With the ratio equal to 1, the resistance in the arm R should be equal to the resistance X in S. Thus the two numbers between which the resistance X lies is known.

4. Next make the ratio 10 by taking out P = 100 and Q = 10. Adjust the resistance of the arm R again for right and left deflection with a difference of one ohm resistance in R. The value of R will be ten times

that of S. Divide this resistance in R by 10 to get the value of unknown resistance to the first place of decimal.

5. Finally keep the ratio 100 by taking out P = 1000 and Q = 10 and adjust R (which will be ten times of the value in the last case) as before to get opposite deflections with two resistances differing by one ohm only. If the arrangement is not very sensitive, this may not give any change in deflection for a change of one ohm, try to get deflections in opposite directions with two resistances of the arm R which differ by the least possible value. Determine the unknown resistance to the third place of decimals by the *method of proportional parts e.g.*, 736 ohms give a deflection of 3 divisions in one direction and 739 ohms give a deflection of 2 divisions in the opposite direction, a difference of 3 ohms in R causes a change of 5 divisions. Hence a resistance of $736 + \frac{3\times3}{5} = 737{\cdot}8$ ohms will produce a balance and value of the unknown resistance X will be 7·378 ohms but such a high degree of accuracy cannot be claimed from a P.O. box.

Sometimes it happens that for a change from a lower to a higher ratio the resistance required in the arm R for a balance does not lie between the expected limits. This may be due to inaccuracy in the value of the coils resistance or contact resistance. The contact resistance can be much reduced by tightening the plugs in a plug type of box. The value of resistance X obtained with higher ratio should be accepted.

6. Determine the radius of the wire at different places in mutually perpendicular directions by screw gauge and also measure its length by metre rod by leaving out the portions of the wire which were pressed under the terminals. Calculate its sp. resistance for the given material of the wire as given in theory.

Observations :

Position of the galvanometer pointer = ... div.

Table for the resistance of the wire

S. No.	Ratio Arms		Rheostat Arm R in ohms	Direction of deflection	Resistance X in ohms
	P	Q			
			7	Right	
1	10	10	8	Left	lies between 7 & 8
			73	Right	
2	100	10	74	Left	lies between 7.3 & 7.4
3	1000	10	737	Nil	7·37

Resistance X of the wire = 7.37 ohms (*The mean of all the three readings should never be taken*).

Length of the wire l = 41·2 cm (say)

Pitch of the screw p = ... mm

No. of circular divisions n = ... div.

Least count p/n = ...mm

Zero error of the screw gauge (1) = ... mm

(2) =.............. mm

(3) =.............. mm

Mean zero correction = ... mm

Table for Diameter of the Wire

S.No.	One direction			Mutually Perpen dicular direction			Mean correct diameter in cm
	Main Scale reading in m m	No. of C.D Coinciding	Observed diameter in m m	Main Scale reading in m m	No. of C.D. Coinciding	Observed diameter in cm	
1.							
2.							
3.							
4.							

Radius of the wire $r=\frac{d}{2}=0{\cdot}014$ cm. (say)

Calculations:

Sp. resistance of the material of the give wire

$$K = X.\frac{\pi r^2}{\ell}$$

$$= \frac{7{\cdot}37 \times 3{\cdot}14 \times (0{\cdot}014)^2}{41{\cdot}2}$$

$$= \frac{7{\cdot}37 \times 3{\cdot}14 \times 196}{41{\cdot}2} \times 10^{-6}.$$

Let $x=\frac{7{\cdot}37\times3{\cdot}14\times196}{4{\cdot}12}$

$$\log x = \log 7{\cdot}37 + \log 3{\cdot}14 + \log 196 - \log 41{\cdot}2.$$

$$= 0{\cdot}8675 + 0{\cdot}4969 + 2{\cdot}2923 - 1{\cdot}6149$$

$$= 3{\cdot}6567 - 1{\cdot}6149 = 2{\cdot}0418$$

$\therefore$ $x = 110{\cdot}1$

Hence $K = 110{\cdot}1 \times 10^{-6}$ ohm/cm^3

Result :

Sp. resistance of the material of the given wire (Nichrome)

$= 110{\cdot}1 \times 10^{-6}$ ohm/cm^3

Actual value $= 110 \times 10^{-6}$ ohm/cm^3

Error $= 0{\cdot}0\%$

Precautions :

1. The galvanometer should either be shunted or a resistance box should be connected in series with it. Shunt or resistance should not be used near the balance point.

2. The mean of three readings should never be taken.

3. The length of the wire should be measured from the points where the wire comes out of the terminals.

4. All the plugs should be tight.

5. First the battery key K_1 and then the galvanometer key K_2 should be pressed.

Sources of Error :

1. Contact resistance in dial type, they are sufficiently reduced.

2. Heating of the wire increases the resistance.

3. Resistance of the coils of the P.O. box may not be standard.

ORAL QUESTIONS

(See Expt. No. 3)

EXPERIMENT 6

To study the laws of resistances in series and in parallel using Post Office Box.

Proceed same way as in Expt. 5. Find R_1. Remove first resistance R_1 and put second resistance R_2. Find R_2.

Now put R_1 and R_2 in series and find R_S. Then put R_1 and R_2 in parallel and find R_p.

Observations and Calculations :

Resistance	S. No.	Ratio Arms		Rheostat arm R in ohms	Direction of Deflection	Resistance in ohms
		P	Q			
R_1	1 2 3	10 100 1000	10 10 10			
R_2	1 2 3	10 100 1000	10 10 10			
R_1 and R_2 in series (R_S)	1 2 3	10 100 1000	10 10 10			
R_1 and R_2 in parallel (R_p)	1 2 3	10 100 1000	10 10 10			

Verification :

$R_1 + R_2 =$ ....ohm

$R_s =$........ohm

As $R_s = R_1 + R_2$; the law of resistances in series is verified.

Again, $\frac{1}{R_1} + \frac{1}{R_2} =$ ......

$\therefore \quad \frac{R_1 \; R_2}{R_1 + R_2} =$........ ohm

$R_p =$ ....ohm

Since $R_p = \dfrac{R_1 R_2}{R_1 + R_2} \left[\text{or } \dfrac{1}{R_p} = \dfrac{1}{R_1} + \dfrac{1}{R_2} \right]$ so the law of resistances in parallel is verified.

Precautions : Same as in Expt. 5.

Sources of Error : Same as in Expt. 5.

ORAL QUESTIONS

(Same as in Expt. 3)

Q. 1. *What is a post office box ?*

Ans. See theory of Expt. 5.

Q. 2. *What is the principle on which post office box works ?*

Ans. See theory of Expt. 5.

□□

EXPERIMENT 7

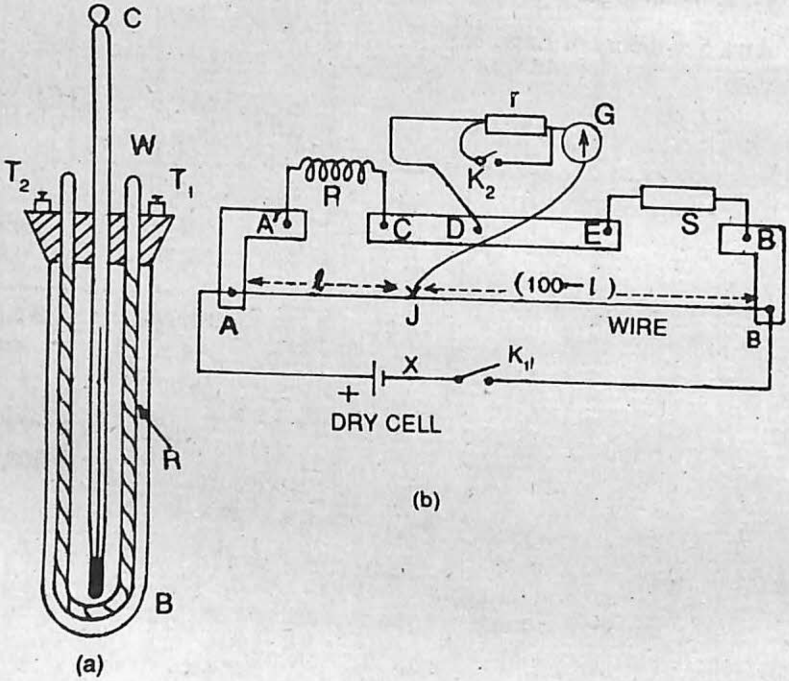
To study the temperature dependance of a resistance (Iron wire/ thermister)

OR

To measure the temperature coefficient of a resistance.

Apparatus :

Metre-bridge (or slide wire bridge); dry cell X, one way key K_1; galvanometer G with protective high series resistance r and shorting key K_2, jockey J, Coil of iron wire R, thermometer 0—100°C, C; large beaker, bunsen, tripod, gauze, ice, stirrer, standard resistance S.



(a)

(b)

Fig. 7.1.

Theory :

The ratio of the difference of potential between two points of a wire to the current through the wire is constant only when the temperature is constant. In other words, *the resistance of a wire varies with temperature, and, in general, the resistance at a higher temperature is greater than the resistance at a lower temperature.* The increase of resistance per degree rise of temperature is approximately constant for the same wire. *The coefficient of increase of resistance with temperature is the increase of resistance per degree, divided by the resistance at 0°C.*

Thus, if R_0 = resistance at 0° C

and R_t = resistance at t° C,

the *mean* value of the coefficient over this range is

$$\alpha = \frac{R_t - R_0}{R_0 t}$$

Thus, if α is constant,

$$\boxed{R_t = R_0 (1 + \alpha t)}$$

Thus to study the temperature dependence of a resistance, it is necessary to measure the resistance at various temperatures.

Procedure :

1. Draw a neat circuit diagram showing the connections to the made as shown in Fig. 7.1.

2. Connect up the metre-bridge circuit for measuring the resistance R of the coil W at various temperatures and whose temperature coefficient of resistance is required. Connect the cell X and the Key K_1 to the terminals A, B at the ends of the resistance wire AB. Connect the galvanometer G, through the protective resistance r (not less than 1000Ω) to the centre terminal D of the heavy brass strip CDE. Carefully clean the terminals C, E and A′ , B′ with fine emery paper and connect the coil W of unknown resistance R and S, a suitable known standard resistance, about the same resistance as W at room temperature by short, cleaned, thick wires to C and A′ and E and B′ respectively, so that as little extra resistance as possible is introduced. The protective resistance r is either a high (radio-type) resistance in series as shown, or a rheostat of a few ohms connected in parallel with the galvanometer.

3. Immerse the coil W in crushed, melting ice in a large beaker (see Note (ii) at the end of this procedure if ice is not available). Wait until the temperature of W is steady at 0° C. Close the key K_1 and locate the balance point by touching the jockey J lightly onto the bridge wire AB

When the position of the balance point has been found to the nearest cm short the protective resistance by K_2 and locate the balance point as accurately as possible. Measure the length l from the end A to the balance point and record it at this temperature.

4. Warm the ice until it melts, add water to the beaker, and measure the new balance length when the temperature has risen about 10 K and is steady. Record the exact value of the temperature. Continue to warm the water further, maintain the temperature steady at a series of temperatures upto about 90°C, and record the balance length at each temperature.

5. Allow the water to cool, adding cold water if necessary, and repeat the measurement of the balance lengths at the temperatures previously recorded so that an *average value* can be found.

Notes :

(*i*) *The bridge is insensitive when the balance point is not near the centre of the wire AB. If necessary, the known resistance S should be replaced by one which gives a balance point between 30 and 70 cm of the wire.*

(*ii*) If ice is not available, produce the graph (Fig. 7.2) back to the R_t axis to find R_0, the resistance at 0°C.

(*iii*) A suitable resistance coil may be constructed by winding a length of thin iron wire on a bent glass rod, soldering the ends to the terminals T_1, T_2, secured in a cork [See Fig. 7.1 (*a*)]. A hole in the centre of the cork takes a thermometer C, and the whole is enclosed in a boiling tube B, which may be filled with a light oil to improve the thermal contact. Alternatively, the coil should be well varnished, when it may be immersed directly in a water bath. Thin copper wire, preferably enamelled may also be used.

Observations and Calculations :

S. No.	Temperature t°C	Position of the balance point (J) cm	Length (AJ) $= l$ cm	Length $(100 - l)$ cm	Resistance S (ohms)	Resistance $R_t = \frac{l}{(100-} \times s$ (ohms)
1			--- ---} Average = --- cm	--- ---} Average = ---cm		
2			--- ---} Average = --- cm	--- ---} Average = ---cm		
3						
4						
5						
6						
7						

Plot a graph of the resistance R_t versus temperature t in °C, and draw the best straight line, as shown in Fig. 7.2.

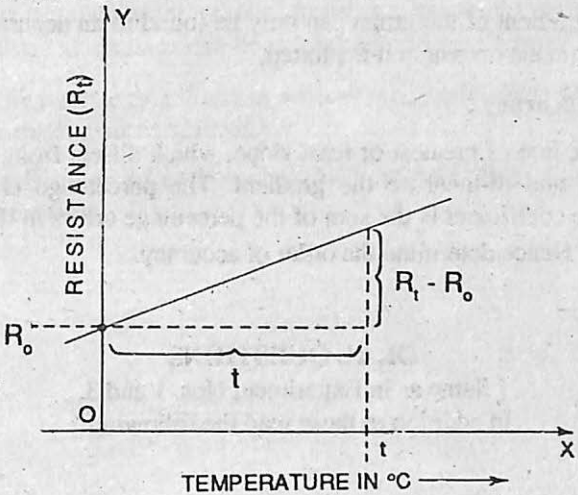


Fig. 7.2.

The temperature coefficient of resistance $\alpha = \dfrac{R_t - R_o}{R_o \times t}$

$$\text{But } \frac{R_t - R_o}{t} = \text{gradient of graph}$$

$$\therefore \alpha = \frac{\text{gradient of graph}}{R_0} = \text{------}$$

Result :

(a) The resistance of the wire varies with temperature. *The resistance of the iron wire increases with the rise in temperature.* The resistance at a higher temperature is greater than the resistance at a lower temperature.

(b) The temperature coefficient of resistance of the iron wire = ... K^{-1}

Precautions :

Same as in Experiment 2.

Sources of Errors:

1.
2. } Same as in Experiment 2.
3.

4. The thermometer may be read to, say, ± 0·1 K (a much larger percentage error).

5. The coil may not be at the temperature indicated by the thermometer.

6. The gradient of the graph can only be found to an accuracy limited by the scale on which it is plotted.

Order of Accuracy :

Draw the line of greatest or least slope, which differs from that of the 'best' line, and re-measure the gradient. The percentage error in the temperature coefficient is the sum of the percentage errors in the gradient and in R_o. Hence determine the order of accuracy.

ORAL QUESTIONS

[Same as in Experiment Nos. 1 and 3.
In addition to these read the following.]

Q. 1. *What is the formula for the variation of resistance with temperature ?*

Ans. For *lower* ranges of temperature, say, up to 400° C the variation is *linear* and is represented by the formula $R_t = R_0 [1+\alpha t]$

Q. 2. *And if the temperatures are higher, then what is the formula?*

Ans. Then the variation is *parabolic*. In this case the formula is $R_t = R_0 [1+ \alpha t + \beta t^2]$ where β is another constant whose value is very small. Hence the effect of this term becomes prominent only at *high* temperatures.

Q. 3. *What do you mean by temperature coefficient of resistance ?*

Ans. The temperature coefficient of resistance of a material is equal to the increase in the resistance of a wire of that material per unit resistance per degree centigrade rise in temperature. Mathematically, we can express it as,

$$\alpha = \frac{R_t - R_o}{R_o \times t}$$

Q. 4. *What is the unit in which this α is expressed ?*

Ans. Its unit is "*per degree centigrade*".

Q. 5. *Why is it advised that we should take readings when the temperatures are falling, and why not only when the temperatures are rising ?*

Ans. It is simply due to the reason that it is easier to take readings when the temperature is falling than when it is rising. While falling temperature remains constant at one particular value for some time during which interval readings can be quickly taken.

Q. 6. *Can you tell any substance whose resistance decreases with temperature instead of increasing with it ?*

Ans. Yes; a filament of carbon shall have its resistance diminished when temperature rises.

□ □

EXPERIMENT 8

To compare Electro-Motive-Force's (E.M.Fs.) of two primary cells using a potentiometer.

Apparatus :

A potentiometer with sliding key (or Jockey); a Leclanche cell; a Daniell cell; an ammeter; a low resistance Rheostat; a one-way-key; a galvanometer; a resistance box; a battery of 2 to 3 accumulators (or E.M.F. higher than the E.M.F. of individual cell to be compared) ; a voltmeter; connecting wires; a two-way key and a piece of sand paper.

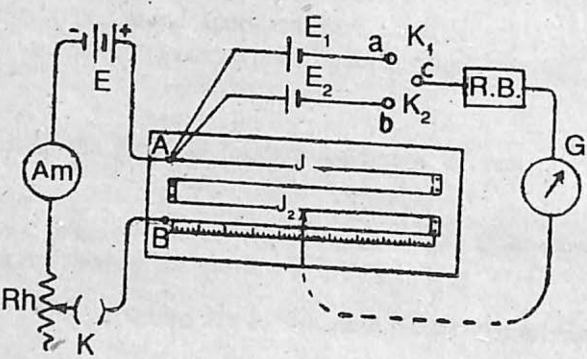


Fig. 8.1. Comparison of e.m.fs of two cells

Theory :

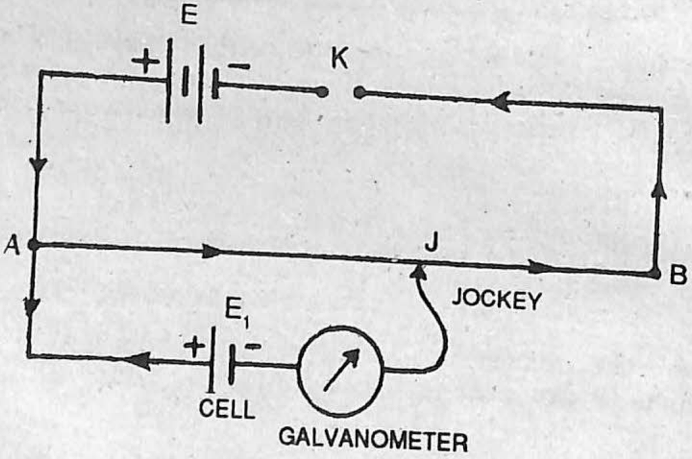


Fig. 8.2. Principle of potentiometer

Potentiometer is an instrument designed for an accurate comparison of potential differences and for measuring small potential differences. In an ordinary form it consists of a long, uniform resistance wire of manganin or constantan stretched over a wooden board usually in 4 turns (or 10 turns) each of 100 cm length. The wire is fixed at its ends to two binding screws. A metre-scale is fitted parallel to the wire and a sliding key or jockey is provided for contact.

The working of a potentiometer can be understood by considering a simpler diagram (Fig. 8.2).

Let a wire AB be connected to a source of *constant* potential difference 'E' known as '*Auxiliary battery*'. This source will maintain a current in the wire flowing from A to B and there will be a constant fall of potential from the end A to B. This source thus establishes in the wire a potential difference per unit length known as the *'Potential Gradient'*. If L be the length of the wire, this potential gradient 'ρ' will be $\frac{E}{L}$ volts.

Let one of the cells, whose E.M.F. 'E_1' is to be compared with the E.M.F. 'E_2' of the other cell, be connected with its +ve electrode at A and the other electrode through a galvanometer to a movable contact *i.e.*, jockey J (Fig. 8.2).

If the fall in potential between A and J due to the current flowing in the wire be equal to the E.M.F. 'E_1' of the cell, the galvanometer will show *no* deflection when the jockey is pressed at J indicating no current in the galvanometer. This position on the wire AB is possible only *when E is greater than E_1*.

If the point J be at a distance l_1 cm from A, the fall in potential between A and J will be ρl_1 and therefore,

$$\boxed{E_1 = \rho l_1} \text{ at the null deflection.}$$

If this cell be now replaced by the second cell of E.M.F. 'E_2' and another *balance* be obtained at a distance l_2 cm from A, then

$$\boxed{E_2 = \rho l_2}$$

$$\therefore \quad \frac{E_1}{E_2} = \frac{\rho l_1}{\rho l_2} = \frac{l_1}{l_2}$$

$$\text{or} \quad \boxed{\frac{E_1}{E_2} = \frac{l_1}{l_2}}$$

Since the galvanometer shows no deflection at the null point so no current is drawn from the experimental cell and it is thus the actual E.M.F. of the cell that is compared in this experiment.

Procedure :

1. Draw a diagram showing the scheme of connections as in Fig. 8.1.

2. Remove the insulation from the ends of the connecting copper wires and clean the ends with a sand paper.

3. Connect the *positive pole* of the **auxiliary battery** (a battery of constant *e.m.f.*) to the zero end (A) of the potentiometer and the *negative pole* through a one-way key, an ammeter and a low resistance rheostat to the other end of the potentiometer. Connect the *positive* pole of the cells E_1 and E_2 to the terminal at the zero end (A) and the negative poles to the terminals *a* and *b* of the two way key. Connect the common terminal *c* of the two-way key through a galvanometer (G) and a resistance box (R.B.) to the jockey.

4. *To test the connections :*

Introduce the plug in position in the one-way key (K) in auxiliary circuit and also in between the terminals *a* and *c* of the two-way key. Take out a 2,000 ohms plug from the resistance box (R.B.). Press the jockey at the zero end and note the direction of deflection in the galvanometer. Press the jockey at the other end of the potentiometer wire; if the direction of deflection is *opposite* to that in the first case, the connections are correct.

If the direction of deflection is in the same direction then increase the current in the auxiliary circuit with a rheostat till the deflection obtained in the galvanometer is in the opposite direction when the jockey is pressed at the other end.

5. Move the jockey along the wire from the zero end A towards the other end B so as to find a point J_1 where the galvanometer shows no deflection.

Put in the 2000 ohms plug in the resistance box and find the *null point accurately*. Note the length 'l_1' of the wire and also the current in the ammeter.

6. Disconnect the cell E_1 and put the cell E_2 in circuit. Again remove 2000 ohms plug from the resistance box and find the null point roughly. Put in the 2000 ohms plug and find the corresponding length (l_2) *accurately* for no deflection of galvanometer *keeping the ammeter reading the same.*

7. Repeat the observations alternately for each cell again for the same value of current.

8. Increase the current by adjusting the rheostat and obtain in a similar way four sets of observations.

(The rheostat used in the circuit should have a low resistance as compared to the resistance of the potentiometer wire.)

9. Find the mean of the two observations for each cell and calculate the ratio $\frac{l_1}{l_2}$.

10. Measure the E.M.F. of the two cells separately with a voltmeter and compare the ratio $\frac{E_1}{E_2}$ with that obtained from the observations with the potentiometer.

Observations and Calculations :

S. No.	Ammeter Reading	Length of wire with						$\frac{E_1}{E_2}=\frac{l_1}{l_2}$
		Cell E_1 (Leclanche cell)			Cell E_2 (Daniell cell)			
		(*i*)	(*ii*)	Mean (l_1)	(*i*)	(*ii*)	Mean (l_2)	
1.	......amperes	...cm	...cm	...cm	...cm	...cm	...cm	
2.								
3.								
4.								
5.								

Mean $\frac{E_1}{E_2}$ = ...

Verification :

E.M.F. of Leclanche cell (E_1) = ... volts
(By voltmeter)

E.M.F. of Daniell cell (E_2) =......... volts
(By voltmeter)

$\therefore \frac{E_1}{E_2}$ = ...

Result :

$$\frac{\text{E.M.F. of Leclanche cell}}{\text{E.M.F. of Daniell cell}} = \ldots\ldots$$

Precautions :

1. The e.m.f. of the auxiliary battery should be constant and always greater than the e.m.f. of either of the two cells, whose e.m.fs. are to be compared.

2. *The positive pole of the auxiliary battery and the positive poles of the cells must be connected to the terminal on the zero side of the potentiometer wire otherwise it would be impossible to obtain a balance point.*

3. The rheostat should be of a low resistance and whenever the deflection shown is to the same side when jockey is pressed at all points of the wire, the current must be increased to obtain the balance point at a desired length.

4. The *current should remain constant* for each set of observations with the two cells.

5. The current should be passed only for the duration it is necessary, otherwise the balance point will keep on changing.

6. The balance points should be obtained at large distances from the zero end.

7. The length should always be measured from the end of the wire where positive poles are connected.

8. The balance point should be found alternately with the two cells.

9. A high resistance should be used in series with the galvanometer. *This does not affect the position of the balance point in any way*. Near the position of the exact balance point, however, this resistance should be removed.

(Note that the same purpose can be served by putting a shunt across the galvanometer.)

10. A resistance box should *never* be used in the auxiliary circuit.

11. To avoid any change in the e.m.f. of a cell due to polarization, the readings should be taken after sufficient intervals of time.

Sources of Error :

(*i*) The potentiometer wire may not be uniform.

(*ii*) The resistance of the wire may change due to rise of temperature.

(*iii*) Contact potentials may not be negligible.

Exercise

Using a potentiometer, find the e.m.f. of a Daniel's cell with the help of a fresh dry cell.

[*A.I.S.S.C., 1980*]

[**Hints** : $\frac{E_1}{E_2} = \frac{l_1}{l_2}$. If E_2 = E.M.F. of dry cell = 1·5 V; find E_1.]

(By voltmeter)

ORAL QUESTIONS

Q. 1. *What is a Potentiometer ?*

Ans. A potentiometer consists of a long uniform wire of constantan or manganin fixed on a wooden board in which a steady current is allowed to flow by connecting it to a source of constant E.M.F.

Q. 2. *Why do we use constantan or manganin wire ?*

Ans. Because they possess *high specific resistance* and low temperature coefficient.

Q. 3. *What is the use of a Potentiometer ?*

Ans. As the name suggests, a potentiometer is employed primarily to measure potential differences accurately or compare E.M.F's of two given cells etc.

Q. 4. *Why is it called a Potentiometer ?*

Ans. Because it measures potential difference between any two points.

Q. 5. *What is the principle of a Potentiometer ?*

Ans. It works on the principle that for constant current, fall of potential along a uniform wire is proportional to its length.

Q. 6. *What is potential gradient ?*

Ans. It is the fall of potential per cm of length of the potentiometer wire.

Q. 7. *Why do we use a Rheostat in the battery circuit ?*

Ans. In order to vary the potential gradient.

Q. 8. *On what factor does the potential gradient depend ?*

Ans. Potential gradient depends directly on the strength of the current and resistance per cm of the wire.

Q. 9. *Do we compare the E.M.F. or P.D. of the two cells by Potentiometer ?*

Ans. We compare E.M.F's and not P.D. because at the null point no current flows through the cells and E.M.F. is equal to P.D. Hence for all intents and purposes, the cell is on open circuit.

Q. 10. *Do you think the cell circuit to be closed or open at the null point ?*

Ans. No current flows through the cell at the null point and hence even if the whole circuit is closed, actually cell circuit is open.

Q. 11. *What do you mean by sensitiveness of a potentiometer ?*

Ans. A potentiometer is said to be sensitive if very small potential differences can be measured by it.

Q. 12. *How can its sensitiveness be increased ?*

Ans. By increasing the number of wires of the potentiometer. In other words, the sensitiveness of a potentiometer increases, if its potential gradient diminishes.

In the case of a potentiometer with a fixed length of the wire, the potential gradient can be diminished by reducing the current in the main circuit with the help of a rheostat.

Q. 13. *So we can reduce the potential gradient indefinitely by reducing the main current progressively and thus attain a high degree of sensitiveness. Is it not so ?*

Ans. No. The potential gradient cannot be reduced indefinitely. The fall of potential over the entire length of the wire should be at least equal to the potential difference to be measured, otherwise it cannot be rebalanced. Moreover, there is no use trying to attain a high degree of sensitivity unless the galvanometer is sensitive enough to detect any want of balance.

Q. 14. *Upon what factors does the accuracy of the potentiometer depend ?*

Ans. The accuracy of the instrument depends upon two factors :

(*i*) Constancy of the E.M.F. of the accumulator.

(*ii*) Uniformity of the potentiometer wire.

(*iii*) Sensitivity of the galvanometer.

Q. 15. *How is accuracy affected by increasing the length of the wire ?*

Ans. Longer the wire, greater is the probability of the wire being non-uniform and hence the instrument is no more quite accurate although its sensitiveness is increassed.

Q. 16. *Is it not better to measure the e.m.f. of a cell by a voltmeter ?*

Ans. No. Truly speaking, the voltmeter does not measure the e.m.f. accurately. In this case a current, however small, is drawn by the voltmeter for its operation and hence we cannot rigorously say that the cell is on open circuit. For an exact measurement of the E.M.F., the voltmeter should have an infinite resistance, a condition which is impossible to achieve with an instrument depending for its action on the magnetic effects of currents.

Q. 17. *Why should the E.M.F. fall when the voltmeter is connected across its terminals ?*

Ans. Let I be the current drawn by the voltmeter, then

$$I = \frac{E}{R + r}$$

or $E = IR + Ir = V + Ir$, where R is the resistance of the voltmeter and 'r' that of the cell. V is the terminal voltage as read by the voltmeter. This will always be less than E unless $Ir = 0$. Now, r can never be zero, hence the only other alternative is that I should be zero *i.e.*, the measuring instrument should draw no current.

Q. 18. *What type of cell should be used in the main circuit ?*

Ans. The cell should have e.m.f. *higher* than any of the cells whose e.m.fs are to be compared. So we use accumulator in the main circuit. It is also capable of supplying a steady current for an appreciably long time.

Q. 19. *Can this work be not taken with a battery of primary cells ?*

Ans. No. This battery may give a high E.M.F. but it will *not give a steady current* for a long time. Hence it is unsuitable for maintaining a constant potential gradient along the potentiometer wire.

Q. 20. *Does your accumulator give an absolutely steady current ?*

Ans. A freshly charged cell of large capacity gives fairly, not absolutely, steady current.

Q. 21. *Even if there is slight variation in the value of the main current, will there be no effect on the potential gradient ?*

Ans. Yes. There is an effect. When the current changes, the potential gradient changes too.

Q. 22. *Then how do you account for this in your experiment ?*

Ans. For this purpose a rheostat is included in the main circuit. The same potential gradient is obtained by getting the null point at the same point of the potentiometer wire by adjusting the rheostat in the main circuit.

Q. 23. *Will you prefer null point on the first wire or the last wire ?*

Ans. On the last wire because the percentage error will be less and the accuracy in the measurement of length will increase.

Q. 24. *Is the null point due to flow of equal and opposite current or no flow of current ?*

Ans. Due to no flow of current.

Q. 25. *Why are the readings given by potentiometer more accurate than those of voltmeter ?*

Ans. Becuase the least count of the potentiometer is much less than that of a voltmeter.

Q. 26. *Why do we use a high resistance in series with the galvanometer ?*

Ans. To make the galvanometer less sensitive in order to locate the null point roughly.

Q. 27. *Why are the positive end of the battery as well as of the cell are connected to the zero end of the potentiometer ?*

Ans. So that the flow of current through the galvanometer due to accumulator and the cell may be in opposite directions.

Q. 28. *What will happen if we connect all the negative poles at the zero end ?*

Ans. If we connect all the negative poles at one terminal, we can perform the experiment but the direction of current in each circuit will get reversed and all the lengths of the wire should be measured from the common terminal.

Q. 29. *What is the formula for comparing E.M.Fs. of two cells by a potentiometer ?*

Ans. $\frac{E_1}{E_2} = \frac{l_1}{l_2}$ where E_1 and E_2 are the E.M.Fs. of the given cells and l_1 and l_2 are the lengths of the potentiometer wire for the two cells where the balance points are obtained.

□□

EXPERIMENT 9

To determine the internal resistance of a primary cell using a potentiometer.

Apparatus :

A potentiometer, a Leclanche cell, a battery of three cells, an ammeter, a low resistance rheostat, two one-way keys, a sensitive galvanometer, two resistance boxes, a jockey, connecting wires and a piece of sand paper.

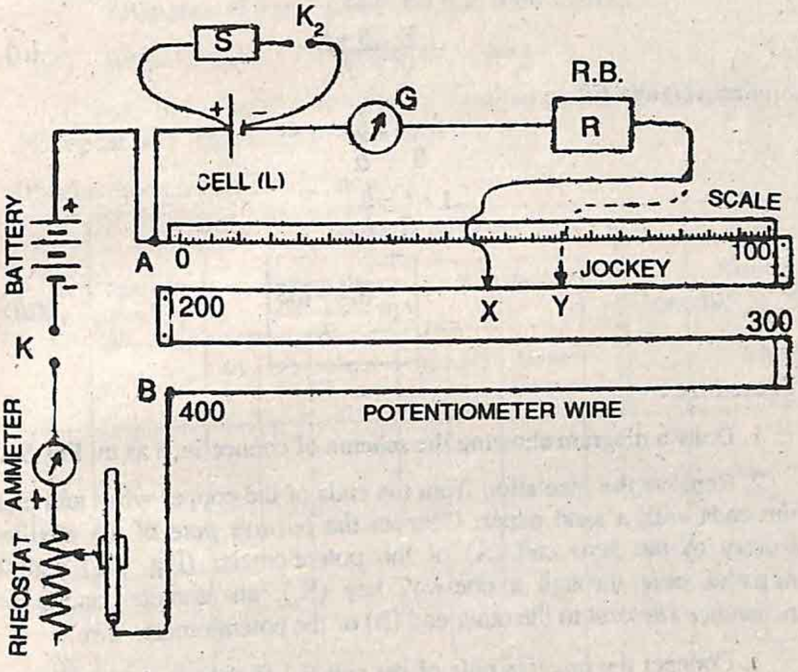


Fig. 9.1. Internal resistance of a cell

Theory :

In the potentiometer circuit of Fig. 9.1 let 'l_1' be the length of the potentiometer wire upto the point X, when balance is obtained with the cell (L) *in open circuit* when key K_2 is not closed and 'l_2' the length upto Y when the balance is obtained with the cell *shunted* through a resistance S. Then if E is the e.m.f. of the cell and 'V' the P.D. between its terminals when shunted, we have according to the principle of the potentiometer (explained in the theory of Experiment No. 8).

$$\text{and } E \propto l_1$$

$$\text{and} \quad V \propto l_2$$

$$\therefore \quad \frac{E}{V} = \frac{l_1}{l_2} \qquad \dots (i)$$

If '*r*' be the internal resistance of the cell and I the current through it when shunted by S, then by Ohm's Law

$$E = I\,(S + r)$$

$$\text{and} \quad V = IS$$

$$\therefore \quad \frac{E}{V} = \frac{S + r}{S} \qquad \dots (ii)$$

From (*i*) and (*ii*)

$$\frac{S + r}{S} = \frac{l_1}{l_2}$$

$$\text{or} \quad 1 + \frac{r}{S} = \frac{l_1}{l_2}$$

$$\text{Whence,} \quad \boxed{r = \frac{(l_1 - l_2)S}{l_2}} \qquad \dots (iii)$$

Procedure :

1. Draw a diagram showing the scheme of connections as in Fig. 9.1.

2. Remove the insulation from the ends of the copper wires and clean the ends with a sand paper. Connect the *positive pole* of the auxiliary battery to the zero end (A) of the potentiometer (Fig. 9.1) and the *negative pole* through a one-way key (K_1), an ammeter and a *low resistance rheostat* to the other end (B) of the potentiometer wire.

3. Connect the *positive pole* of the cell (L) to the terminal at the zero end (A) and the *negative pole* to the jockey through the galvanometer (G) and resistance box (R.B.).

4. Connect a resistance box S across the cell (L) through a one-way key (K_2).

5. *To test the connections :*

Introduce the plug in the key (K_1) *but not in K_2* and test the connections as in Step 4. (Experiment No. 8).

6. (*i*) Move the jockey along the wire so as to find a point where the galvanometer shows no deflection. Insert the 2000 ohms plug and find the null point accurately as at X. Note the length l_1 of

the wire and the current in the ammeter. Put in the key K_2 and take out 2 ohms plug from the resistance box S and make all other plugs tight by giving them a slight twist. Find the balance point again as at Y and note corresponding length l_2.

Repeat twice for the same value of the current in the auxiliary circuit and same shunt resistance in a similar manner.

(*ii*) Remove the plugs from the keys K_1 and K_2. Wait for some time; insert the plug in the key K_1 and find l_1 keeping the current same in a similar manner. Put in the plug in the key K_2, take out a resistance of 3 or 4 ohms and find the length l_2.

(*iii*) Repeat similarly for S equal to 5 ohms.

7. Change the value of current in the external circuit by a slight amount and repeat observations as in Step 6.

Observations and Calculations :

S. No.	Ammeter Reading (amperes)	Position of Null Point						Shunt Resistance (s) ohms	Internal Resistance $r=\frac{S(l_1-l_2)}{l_2}$ (ohms)
		Without shunt			With shunt				
		(*i*)	(*ii*)	Mean (l_1) cm	(*i*)	(*ii*)	Mean (l_2) cm		
1.									
2.									
3.									
1.									
2.									
3.									

Mean '*r*' = ... ohms

Result :

Internal Resistance of Leclanche cell (*r*) = ... ohms

Precautions :

1. Same as in **Experiment 8.**

2. The internal resistance of a Leclanche cell is *not* constant but varies with the current drawn from the cell. Hence to get concordant readings

the resistance from the resistance box S must be varied by a small amount (say 3 to 8 ohms).

[**Note.** To prevent a large current from being passed through the galvanometer either shunt it with a wire or put a large resistance about 2000 ohms in series with it (Fig. 9.1). But when the balance point is located, to find it more precisely the shunt should be removed or all the plugs of the series resistance box should be inserted.]

Sources of Error :

Same as in **Experiment No. 8.**

Exercise

Using a potentiometer find the internal resistance (*a*) r_1 of a Daniel cell; (*b*) r_2 of a Leclanche cell, and (*c*) r of series battery of the cells in (*a*) and (*b*). Find the relation between r, r_1 and r_2.

[*A.I.S.S.C. 1980*]

ORAL QUESTIONS

[For *General Questions* on Potentiometer see **Experiment No. 8.**]

Q. 1. *Which cell we use to find the internal resistance ?*

Ans. Leclanche cell.

Q. 2. *Can we find the internal resistance of a Daniel cell accurately ?*

Ans. It is quite difficult as its internal resistance goes on changing rapidly.

Q. 3. *Why the cell be not disturbed during observation ?*

Ans. Because the internal resistance of the cell changes when it is disturbed.

Q. 4. *How would you know the value of the E.M.F. or voltage i.e., P.D. by simply noting the null point ?*

Ans. This can be calculated by knowing the potential gradient existent along the potentiometer wire. For instance, if ρ is the potential gradient and 'l' is the length of the wire upto the balance point, then the E.M.F. or P.D. is equal to ρl volts.

Q. 5. *What is the principle underlying the procedure you are adopting in this experiment ?*

Ans. The terminal voltage of a cell on open circuit is higher than when a current is being drawn through it. Due to the internal resistance of the cell its E.M.F. shows a fall. If we can measure the E.M.F. (E) and the terminal voltage (V) on closed circuit, we can determine the internal resistance (*r*) of the cell.

Q. 6. *That can be easily done by means of an ammeter and voltmeter method.Is it not ? Then why all this unnecessarily elaborate procedure ?*

Ans. Yes. But due to the inherent shortcomings in these instruments, the ammeter and voltmeter method is not an accurate one. Potentiometer being much more sensitive and accurate has therefore been employed here.

Q. 7. *Why is the balancing length of the potentiometer wire decreased in the second case ? Can it be increased ?*

Ans. No. It is impossible to increase it. In the first adjustment the Leclanche cell is on open circuit and hence it is the E.M.F. which is being balanced. In the second case, when the current is drawn from the cell through the resistance box, the terminal voltage falls down due to the internal resistance of the cell. Hence the balancing length will always be decreased in the case.

Q. 8. *Why do we use high resistance in the galvanometer circuit in this experiment ?*

Ans. It has a special function to perform. It prevents the flow of excessive currents through the galvanometer, as well as it minimises the polarisation in the cell.

Q. 9. *Does high resistance not affect the sensitiveness of the galvanometer ?*

Ans. Yes, it does. The galvanometer becomes less sensitive. It is for this season that this resistance is excluded when the null point is approached.

Q. 10. *What is the harm if the key is kept pressed for an appreciable time in the resistance box circuit ?*

Ans. If kept pressed for an appreciable time, the current shall be kept flowing from the Leclanche cell in the external circuit. The cell will consequently get polarised and a gradual drift in the balance point shall be observed.

Q. 11. *Suppose while noting the null point it is found that it falls on* *one of the connecting strips of the potentiometer. How will you take the reading ?*

Ans. In such a case I shall shift the balance point on to a neighbouring wire by slightly changing the rheostat in the main circuit. But in such a case the total resistance of the battery circuit for the same set of observations of the P.D. between the terminals of the Leclanche cell on open as well as on closed circuit *has to be kept the same.*

Q. 12. *Does this potentiometer method give an accurate value of the internal resistance ?*

Ans. The internal resistance of a cell is a variable quantity depending upon the current drawn from it. It *increases* as the current drawn is increased. However, for a given value of the current, the internal resistance can be determined *fairly accurately* if the null point is obtained *very quickly.*

Q. 13. *What do we mean by the internal resistance of a cell ?*

Ans. It is the resistance offered by the electrolyte between the electrodes of a cell.

Q. 14. *Is the internal resistance of all the cells same ?*

Ans. No. It is different for different cells.

Q. 15. *Does the cell possess different internal resistance when in open circuit or in closed circuit ?*

Ans. The cell possesses the same resistance in both open as well as closed circuit except when it gets polarised.

Q. 16. *On what factors does the internal resistance of a cell depend ?*

Ans. It depends upon :

(*i*) The distance between the plates. It increases with the distance.

(*ii*) The area of the plates immersed in the electrolyte. If area increases, the internal resistance decreases.

(*iii*) The nature of the electrolyte.

(*iv*) The nature of the electrodes.

Q. 17. *Can we find the internal resistance of an accumulator ?*

Ans. No; the internal resistance of an accumulator is so small that this method cannot be used.

□□

EXPERIMENT 10

To study the equivalence of electric and heat energy.

OR

To determine the mechanical equivalent of heat (J) by electrical method (Joule's calorimeter) and calculate the maximum possible error.

Apparatus :

Joule's calorimeter; a battery of accumulators; voltmeter; ammeter; Rheostat of low resistance; a sensitive thermometer; one-way key; stop-watch; physical balance with weight box; water; connecting wires and a piece of sand paper.

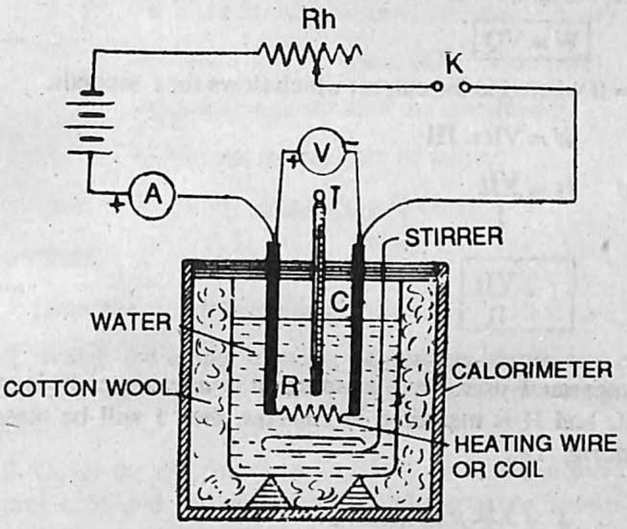


Fig. 10.1. Joule's calorimeter

Theory :

For the first time, Joule (1818-1889) of Manchester, U.K. found in 1848 experimentally that heat is a kind of energy. It can be converted into mechanical energy and *vice versa.* If W is the amount of work done which produces an amount of heat H, then

$$W \propto H$$

or

$$\boxed{\frac{W}{H} = J} \quad \text{.........} (1)$$

where J is a constant of proportionality and is called the *Mechanical Equivalent of Heat.*

If H = 1 calorie, then

$$\boxed{J = W} \qquad \text{..........} (2)$$

Hence Mechanical equivalent of heat is the amount of work done which produces unit calorie (or unit quantity) of heat. Its value is *4·18 × 10^7 ergs/calorie* or *4·18 joules/calorie.*

Heating Effect of Current :

From the definition, it is clear that potential difference V between the ends of a conductor is the work done in bringing a unit charge from one point to the other. If 'Q' units of charge is to be brought from one point to the other, the amount of work done

$$\boxed{W = VQ} \qquad \text{.........} (3)$$

But $Q = It$ where I is the current which flows for t seconds.

$$\therefore \quad W = VIt = JH$$

$$\text{and} \quad H = \frac{VIt}{J}$$

$$\text{or} \quad \boxed{J = \frac{VIt}{H}} \qquad \text{..........} (4)$$

If V is measured in *volts*; I is measured in *amperes* and t is measured in seconds and H is measured in *calories*, then J will be measured in *joules/calorie, i.e.,*

$$J = \frac{VIt}{H} \text{ joules/calorie}$$

$$\text{or} \quad \boxed{J = \frac{VIt \times 10^7}{H}} \text{ ergs/caiorie} \qquad \text{..........} (5)$$

$$(\because \ 10^7 \text{ ergs} = 1 \text{ joule})$$

Joule's Calorimeter :

Joules calorimeter (see Fig. 10.1) consists of a copper calorimeter (with outer surface silvered) which is fitted with an ebonite lid having holes for the stirrer and the thermometer. The lid, supports the heating coil which is suspended inside the calorimeter. The heating wire is made of a material having high resistivity (*e.g.*, eureka or nichrome), and is connected to the lid by thick copper leads. The calorimeter is usually kept in a wooden container, the space in between the two is filled with a non-conducting material *e.g.*, felt; cotton-wool etc, in order to minimise loss of heat due to radiation.

Joule's calorimeter is used to determine the mechanical equivalent of heat (J) with the help of the following formula :

$$J = \frac{W}{H} = \frac{VIt \times 10^7}{H} = \frac{VIt \times 10^7}{[m+w](\theta_2 - \theta_1)} \text{ ergs/calorie} \qquad \ldots\ldots(6)$$

where $W = VIt \times 10^7$ = work done by the electric current,

$H = [m + w](\theta_2 - \theta_1)$ = Heat generated,

V = Potential difference between the ends of the coil,

I = Current flowing through the coil,

t = Time for which current has been flowing in the circuit,

m = mass of water taken in the calorimeter,

w = water equivalent of the calorimeter,

θ_1 = Initial temperature of water,

and θ_2 = Final temperature of water.

Procedure :

1. Draw the circuit diagram as shown in Fig. 10.1.

2. Weigh the empty calorimeter with its stirrer, and again with two thirds of water. The difference between the two masses gives the mass of the water taken.

3. Cover the calorimeter with lid. Fix a sensitive thermometer in the central hole and set up the electrical circuit as shown in Fig. 10.1. Connect the coil, an ammeter; battery; rheostat and one-way key *in series* whereas the voltmeter must be connected in *parallel*. Make sure that the connecting ends are cleaned and the connections are tight. *Positive pole* of the battery must be connected to the *positive terminals* of the ammeter and the voltmeter.

4. After thoroughly stirring the water, note the initial temperature of the cold water.

5. Now switch on the current and immediately start the stop-watch.

6. Note down the potential difference across the heating coil with the voltmeter, and the current with the ammeter *and keep their values constant with the help of the rheostat.*

Keep the water stirring constantly and efficiently. (Efficient stirring is very important in this experiment.)

When the temperature has risen about 6–8° C, switch off the current and immediately note the time. Also note down the final temperature.

7. Allow the calorimeter and its contents to cool *for the same time for which heating was done*, and determine the fall in temperature during the interval. (Continue the stirring of water in this interval).

Add half the fall in temperature to previously observed final temperature of water. *This will give the final temperature corrected for losses of heat by radiation.*

8. Finally calculate the value of J from the formula

$$J = \frac{VIt\times 10^7}{(m+w)(\theta_2-\theta_1)}$$

Observations :

Mass of the calorimeter and stirrer = M = ...g

Mass of the calorimeter + stirrer + water = ...g

Least count of the thermometer = ...°C

Initial temperature of water = θ_1 = ...°C

Least count of the watch = ...s

Initial reading of the watch = ...s

Least count of the ammeter = ...A

Least count of the voltmeter = ...volt

Zero correction of the ammeter = ...A

Zero correction of the voltmeter = ...volt

Corrected Reading of the ammeter = I = ...A

Corrected Reading of the voltmeter = V = ...volt

Final reading of the watch = ...s

Final temperature of water = θ = ...°C

Last temperature of water after cooling for the same time = θ' = ...°C

Calculations :

Mass of cold water = *m* = ...g

Time taken for the experiment = *t* = ...seconds

Fall in temperature after cooling of water for the same time = $(\theta - \theta')$ = ...°C

$\therefore$ Radiation correction = $\frac{1}{2}(\theta - \theta')$ = ...°C

Hence corrected final temperature = $\theta_2 = \theta + \frac{1}{2}(\theta - \theta')$ = ... °C

Hence rise in temperature = $(\theta_2 - \theta_1)$ = ...°C

Specific heat of material of the calorimeter = S = ...

(taken from Table of constants)

$\therefore$ Water equivalent of the calorimeter = ω = MS = ...gm

Now Joule's Mechanical Equivalent of

$$\text{heat} = J = \frac{VIt \times 10^7}{(m+w)(\theta_2 - \theta_1)} = \ldots \text{ ergs/calorie}$$

= ....joules/calorie

Result :

The value of Mechanical Equivalent of heat by Electrical Method (Joule's calorimeter) = ...ergs per calorie = ... joules/cal

i.e., 1 calorie = ...joules

Standard value = $4{\cdot}186 \times 10^7$ ergs/calorie = 4·186 joules/cal

$\therefore$ % Error = ...

Maximum Possible Error :

One student while performing this experiment got the following data :

Current = 2·5 A

Potential Difference = 28·4 volts

Water equivalent of calorimeter (w) = 21 g

Volume of water = 155 cm^3

Initial temperature = 25·6°C

Final temperature = 53·7°C

Time = 298 seconds

$$\therefore J = \frac{VIt}{(m+w)(\theta_2 - \theta_1)} = \frac{I^2Rt}{(m+w)(\theta_2 - \theta_1)}$$

$$= \frac{28{\cdot}4 \times 2{\cdot}5 \times 298}{(21 + 155)\ (43{\cdot}7 - 25{\cdot}6)} = 4{\cdot}279 \text{ joules per calorie.}$$

Errors :

Quantity	Value	Nature of Error	Estimate of Error	% Error
(Current)	2·5	Instrument	± 0·05	± 2%
(P. D.)	28·4	Instrument	± 0·05	± 0·18%
$(\theta_2 - \theta_1)$	28·1	Instrument	± 0·5	± 1·8%
t	298	Instrument	± 0·5	—
			Possible error = ± 3·98%	

$$\text{Error in } J = \pm \frac{3{\cdot}98}{100} \times 4{\cdot}279 = \pm\ 0{\cdot}17$$

Conclusion : J = (4·279 ± 0·17) joules /calorie

Precautions :

(*i*) While setting up the electrical circuit care should be taken to connect properly the ammeter and the voltmeter. Their positively marked terminals should be connected to the higher potential point of the circuit. The ammeter should be connected in series, while the voltmeter should be connected in parallel with the heating coil.

(*ii*) *The potential difference across the heating coil should not be very high*; otherwise electrolysis of water, which sets in, shall effect the result seriously.

(*iii*) The current should be kept constant throughout the duration of the experiment with the help of the rheostat.

(*iv*) The water in the calorimeter should be constantly and efficiently stirred during its heating as well as its cooling when radiation correction is being applied.

(*v*) The final temperature of the calorimeter and its contents should not go more than 8°C above the room temperature, otherwise heat losses should be enormous. Moreover, the observed final temperature should be corrected for the radiation losses.

(*vi*) A sensitive thermometer reading upto at least one-tenth of a degree should be employed.

Sources of Error :

The chief sources of error in this experiment are :

(*a*) heat losses cannot be completely eliminated,

(*b*) the thermal capacity of the heating coil and the thermometer has not been taken into account,

(*c*) loss of heat by evaporation of water has not been considered,

(*d*) part of the total current flowing through the ammeter flows through the voltmeter, so that the current actually flowing through the heating coil is less than the observed value,

(*e*) current and potential difference may not be constant during the experiment due to the change in resistance of the coil.

ORAL QUESTIONS

Q. 1. *What is 'J' or Joule's mechanical equivalent of heat ?*

Ans. J or the mechanical equivalent of heat is the ratio of the work done (W) to the heat generated (H).

$$J = \frac{W}{H}.$$

Q. 2. *What is the unit of J ?*

Ans. joules/calorie or ergs/calorie.

Q. 3. *What is the standard value of J ?*

Ans. 4·186 joules per calorie or $4{\cdot}186 \times 10^7$ ergs/calorie.

Q. 4. *While doing this experiment the ratio $\frac{W}{H}$ should not be called mechanical equivalent of heat, because we do not see any mechanical motion here. It may be called electrical equivalent of heat. Do you agree to this ?*

Ans. No. The argument is not sound. Here also the heat is generated when the mechanical energy of the flowing electrons disappears and work is done by them.

Q. 5. *Explain clearly how work is being done here ?*

Ans. We know that the flow of electrons in a conductor constitutes an electric current. When a potential difference is applied at the ends of the conductor, these electrons begin to flow. These electrons have to pass through the interatomatic spaces, and in so doing experience some resistance to overcome for which they have to do work which appears in the form of heat in the conductor.

Q. 6. *Upon what factors does the amount of work done depend and why ?*

Ans. As the work done by the electrons depends upon the resistance overcome by them during their journey, it will obviously depend upon the number of electrons flowing. Greater the number of electrons flowing—that is, stronger the current—greater is the work done. Similarly, greater the resistance offered by the conductor to the flow of electrons, greater will be the work done. Lastly, longer the time for which the electrons flow, greater will be the work done.

Hence the work done in this case depends upon *three factors* :

(*i*) **Current,**(*ii*) **Resistance,** and (*iii*) **Time.**

Q. 7. *Which of the three quantities contributes most to the production of heat through the conductor? Why ?*

Ans. The current controls the production of heat most.

According to Joule's Laws the heat produced in a conductor is propotional to the *square* of the current, while it varies *linearly* with the resistance as well as the time.

Q. 8. *Where is the conductor in your apparatus ?*

Ans. It is in the form of a coil immersed in water in the calorimeter.

Q. 9. *What is the material of the conductor and why is it chosen ?*

Ans. Nichrome, an alloy of nickel and chromium is the material of the conductor. It is preferred because it has a very high *resistivity*.

Q. 10. *Can you tell the value of its resistivity ?*

Ans. 110×10^{-6} ohms-cm.

Q. 11. *What other materials can be employed for this conductor ?*

Ans. Any material which has a high resistivity can be employed here *e.g.*, constantan, manganin etc.

Q. 12. *How is heating wire connected to the electrical circuit ?*

Ans. The heating wire is connected *in series* in the electrical circuit.

The heating wire is soldered to the end ot the two thick copper rods which are provided with two binding terminals which are connected in series to the external electrical circuit.

Q. 13. *Is there any special reason in connecting the wire with copper rods and should they necessarily be thick ?*

Ans. Yes. Thick copper rods are necessary since their resistance will be negligible in this case. Consequently no heat shall be produced in them. Part of the rod is also immersed in water in the calorimeter.

Q. 14. *Then why not connect the wire directly to the top terminals and dispense with the rods completely ?*

Ans. No. This procedure shall be still more erroneous.

Q. 15. *Why ?*

Ans. In this case the heat produced by the electric current shall not be completely absorbed by water, since the coil cannot be completely immersed in it.

Q.16 *Why should the current pass through the resistance wire, when an alternative path i,e., water is available ?*

Ans. As compared to the resistance wire, water is a poorer conductor. Moreover, the potential difference which we are applying at the ends of the wire, is not sufficient to make the water conducting. If it exceeds 8 volts, a part of the current shall also pass through water which will consequently be electrolysed.

Q. 17. *Are there any sources of error in your experiment ?*

Ans. Yes.

Q. 18. *What are they ?*

Ans. The various sources of error are :

(*i*) The heat produced by electric current is not completely absorbed by the surrounding water and the calorimeter. Some heat is taken by the thermometric bulb and the coil itself.

(*ii*) Loss of heat by evaporation of water has also not been taken into account.

(*iii*) Part of the electric current flowing through the ammeter flows through the voltmeter, so that the current actually flowing through the heating coil *is less* than the observed value.

(*iv*) Some of the heat is lost to the surrounding cotton-wool, wooden enclosure etc. This heat loss is very difficult to evaluate. However, the heat lost to the surrounding medium by radiation can be accounted for.

Q. 19. *How do you account for the radiation losses ?*

Ans. After noting down the final temperature, the liquid is allowed to cool for the same time as was taken in passing the current. The fall in temperature, say δθ, is noted during this interval. Half of this fall (*i.e.* $\frac{\delta\theta}{2}$ is added to the final observed temperature of the calorimeter, and its contents, which gives final temperature corrected for heat losses due to radiation.

Q. 20. *Why should the fall (δθ) be halved and then added ?*

Ans. Heat is lost by radiation throughout the whole interval when the temperature of the calorimeter and its contents is continuously rising. At the initial temperature (θ_1), the rate of cooling is zero, since there is no difference of temperature between the calorimeter and its surrounding medium. At the final temperature (θ_2) the rate of cooling is maximum. Hence the cooling during this interval can be taken as the mean of the coolings at the initial and final temperatures. This is clearly equal to half the cooling at the final temperature.

It is for this reason that we add δθ/2 and not δθ.

Q. 21. *Is it an accurate method in your opinion ?*

Ans. No. It is not.

Q. 22. *How much rise of temperature should you allow in this experiment ?*

Ans. Say, between 6° — 8°C; because if the rise is greater than this, losses of heat become more pronounced and the result will be less accurate.

Q. 23. *Can you name any other experiment which is more accurate than this ?*

Ans. Yes. Callendar and Barne's continuous flow calorimeter is an accurate apparatus for determining 'J'.

□□

EXPERIMENT 11

To determine the Electro-Chemical Equivalent (e.c.e.) of Copper using Copper Voltameter.

Appratus :

Copper voltameter; rheostat; one-way key; accumulator (or battery eliminator) ; stop watch; ammeter and connecting wires.

Theory :

Electrolysis

Except mercury, all pure liquids are bad conductors of electricity. But when there is a metallic salt or an acid in solution, the conductivity of the liquid increases. When a salt is dissolved in solution, its molecules break up into two parts, one of which is positively and the other negatively charged. This process of breaking up of molecules into two parts is called *dissociation* and each part is known as *ion*. The process of decomposition of a compound by an electric current is called *electrolysis*. The liquid containing the substances in solution undergoing decomposition is called *electrolyte*. The vessel in which the electrolysis is carried out, is called an *electrolytic cell or a voltameter*. The two metallic conductors used within a voltameter for the entrance and exit of the current, are called the *electrodes*. The electrode by which the current enters the electrolytic cell is called the *anode* while the other by which the current leaves the cell is called the *cathode*. Ions which appear at the anode are called *anions*, while those at the cathode are called *cations*.

Copper Voltameter

It consists of a glass vessel containing 16 to 22% solution of copper sulphate with a few drops of sulphuric acid. The anode consists of a pair of a copper plates A, A Fig. 11.1 connected together by a simple binding screw and the cathode C is a well cleaned copper plate placed within the two anode plates but not touching them. The cathode is also provided with another binding screw. The two binding screws rise through an ebonite plate forming the lid of the voltameter vessel.

Faraday's Laws of Electrolysis :

1. *The amount of ions liberated from an electrolyte at each electrode is proportional to the quantity of electricity which passes through it, i.e., proportional to the product of the current strength (I. amp) and the time (t second) during which the currrent flows.*

If Q amount of charge flow for *t secs*, deposits a quantity *m gm* of a substance from an electrolyte, then

$m \propto Q$ *i.e.*, $m \propto I.t.$

or $\boxed{m = Z.\ It.}$ where Z is a constant and is called the *electrochemical equivalent of the substance.* It is the mass of an element in grammes which is liberated when a current of one ampere flows for one second through an electrolytic solution containing that substance.

2. *If the same quantity of electricity passes through several electrolytes, the amounts of ions liberated at different electrodes are proportional to their chemical equivalents.*

Since $m = ZIt$

$$\therefore Z = \frac{m}{I.t},$$

where Z = electro-chemical equivalent of copper (*e.c.e.*),

m = mass of copper deposited on the cathode,

I = current in amperes passed in electrolyte,

and t = time in seconds for which the current flows.

Procedure :

Draw a neat diagram indicating the plan of the connections as in Fig. 11.1. Clean the cathode plate with a piece of sand paper so that it becomes perfectly smooth and weigh it accurately. Suspend an extra copper plate in the copper voltameter for the cathode and complete the circuit containing an accumulator, rheostat R, key and an ammeter A taking care that the current enters the voltameter at the anode marked A.

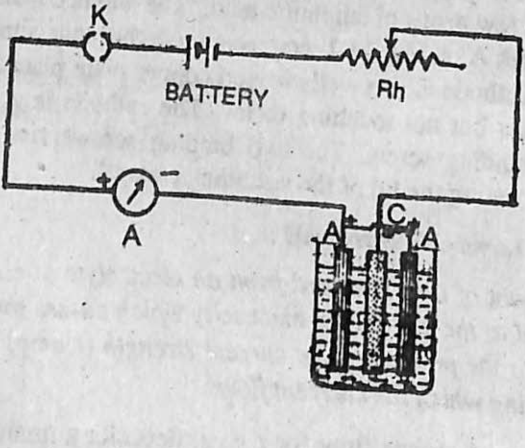


Fig. 11.1. Copper Voltameter

See for some time that the current remains constant. Now replace the extra cathode by the clean-dry and weighed plate, start the stop-watch and insert the plug in the key K.

After passing a constant current for 30 minutes, remove the plug and take out the cathode. Wash it well with tap water, dry it in *shadow* and weigh it again accurately. The increase in weight of the plate gives the mass of copper deposited.

Observations :

Mass of the cathode before expt. = ...g

Current strength (I) by ammeter =.....amp

Time (t) for which the current is passed =........s

Mass of the cathode after expt. =.......g

Mass of copper deposited (m) =........g

Calculations :

$Z = \frac{m}{I.t} = ...g/C$ =.......kg C^{-1}

Electro-chemical equivalent of copper = ...kg C^{-1}

Error = ... %

Precautions :

1. The cathode should be thoroughly cleaned with sand paper.

2. A few drops of sulphuric acid should be added to copper sulphate solution to increase ionization.

3. The current should remain constant throughout the experiment.

4. At the end, the cathode should be washed with slow stream of tap water and then dried in shadow.

5. The plates should not touch each other.

Note. *The strength of the current through the voltameter should not be more than one ampere for every 50 cm² of the cathode and this should be tested before starting the experiment. If the current is too strong, the deposit of copper is not smooth and copper particles fall into the solution whereas if the current is too weak, the mass of copper deposited is too small.*

ORAL QUESTIONS

Q. 1. *What is Electrolysis ?*

Ans. It is a process of decomposing an electrolyte by the passage of current.

Q. 2. *What is a Voltameter ?*

Ans. It is a vessel in which the process of electrolysis is carried out.

Q. 3. *What are Electrodes ?*

Ans. The metallic conductors through which the current leaves or enters the electrolyte are called electrodes.

Q. 4. *What do you mean by Anode and Cathode ?*

Ans. The electrode at positive or higher potential is called anode (Greek *ana*, up) and the electrode at negative or lower potential is called cathode (Greek *kata*, down). Current flows through an electrolyte from the anode to the cathode. Positive ions deposit at cathode and negative *ions* deposit at anode.

Q. 5. *Can electric current pass through all liquids ?*

Ans. The current is able to pass through only those liquids which contain ions.

Q. 6. *Is there any liquid which is conducting yet it does not ionise ?*

Ans. Yes, mercury is such a liquid. It is a very good conductor of electricity, yet it does not ionise.

Q. 7. *What are ions ?*

Ans. When a substance is dissolved in water and current is passed through it, its molecules break up into their components called *ions*. (Greek, *ion*, a wanderer). The ions which are liberated at the cathode are called *cations* while those which are liberated at the anode are called *anions*. Ions are, therefore, electrically charged particles.

Q. 8. *State Faraday's Laws of Electrolysis.*

Ans. *1st Law :*

The amount of ions liberated at the electrodes is proportional to the strength of the current and the time for which it is passed through the electrolyte.

2nd Law :

When the same quantity of electricity flows through a number of electrolytes, the masses of the various ions liberated on the electrodes are directly proportional to their chemical equivalents.

Q. 9. *What is meant by Electro-Chemical Equivalent (e.c.e.) of an element ?*

Ans. From the 1st law of electrolysis

$$m \propto It \propto Q$$

or $$m = ZIt$$

$= ZQ$ where Z is constant of proportionality and is called Electro-Chemical Equivalent *(e.c.e.)*

Hence *e.c.e.* of an element or a substance may be defined as the mass of it which is liberated when one coulomb of electricity flows through the electrolyte.

Q. 10. *What is the unit of e.c.e ?*

Ans. Kilogram/coulomb or kg/C.

Q. 11. *What is electroplating ?*

Ans. It is a process by which a thin coating of some precious metal is deposited by electrolysis on another metal which is cheap and is easily spoiled by exposure.

Q. 12. *Why do we make the article to be electroplated as cathode ?*

Ans. Because the metal radical of the electrolyte is positively charged and hence the positive ions must get deposited on the cathode.

Q. 13. *Why is the article to be electroplated thoroughly cleaned ?*

Ans. If the article is not thoroughly cleaned, the deposit will not be uniform on account of the impurities like grease, etc.

Q. 14. *Can we electroplate a non-conducting object? If so how ?*

Ans. The object is first made conducting by covering it with a layer of graphite and then it is made the cathode.

Q. 15. *Why do we insert an ammeter and Rheostat in a circuit for electroplating ?*

Ans. An ammeter is used to know the strength of the current flowing and a rheostat to adjust a current of desired strength of constant value.

Q. 16. *What should be the order of the current to be passed for a good deposit ?*

Ans. Usually one ampere current for 50 cm^2 of area of the cathode dipping in the electrolyte is passed.

Q. 17. *Why do we use two anodes one on either side of the article to be electroplated ?*

Ans. So that deposit may take place on both sides of the article to be electroplated.

Q. 18. *What kind of deposit is obtained if we use a strong current ?*

Ans. The deposit will be spongy and brittle.

Q. 19. *What happens if the current is unsteady ?*

Ans. The deposit will not be uniform but will be spotted.

Q. 20. *Why do we rinse the plate in dilute sulphuric acid and then wash it immediately after electroplating it ?*

Ans. The article is thoroughly washed after dipping it in dilute sulphuric acid so that the fresh deposit is not oxidised.

Q. 21. *Why do we use an accumulator and not a Leclanche or Daniell cell for electroplating ?*

Ans. Because we need a large and steady current for a uniform deposit.

Q. 22. *Why is cathode made of copper ?*

Ans. In order to avoid back *e.m.f.*

Q. 23. *Why are a few drops of sulphuric acid added to copper sulphate solution ?*

Ans. This furnishes additional ions in the solution and thus increases the conductivity of the solution.

Q. 24. *Name some of the applications of electrolysis.*

Ans. Electroplating; Electrotyping; Anodizing; Gramophone records; Electrochemical processes, etc.

Q. 25. *What is the difference between an ion and an atom of element ? Give an example.*

Ans. There is a fundamental difference between an ion and an atom of an element. For instance sodium ion does not react with water, where as neutral sodium atom reacts vigorously with water. In an electric field the sodium ion drifts towards the cathode, strikes against it and picks up an electron from it. Thus it is converted here in a neutral atom which then reacts with water near the electrode.

□□

*EXPERIMENT 12

To find the resistance of a galvanometer by half deflection method.

Apparatus :

A weston type moving coil galvanometer; a cell; two resistance boxes; two one-way keys; connecting wires and a sand paper.

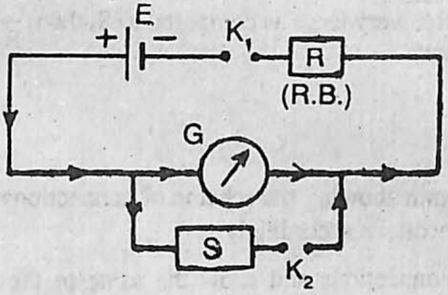


Fig. 12.1. Half deflection method

Theory:

The connections for findings the resistance of a galvanometer by the half deflection method are shown in Fig. 12.1. When the key, K_1 is closed, keeping the key K_2 open, the current I_g through the galvanometer is given by

$$I_g = \frac{E}{R+G}$$ where E = E.M.F. of the cell.

R = Resistance from the resistance box R.B.

G = Galvanometer resistance.

If θ is the deflection produced, then

$$\frac{E}{R+G} = K\theta \qquad \text{.......}(i)$$

If now the key K_2 is closed and the value of the shunt resistance S is adjusted so that the deflection is reduced to *half* of the first value, then current flowing through the galvanometer I_g is given by

$$I_g = \frac{E}{R + \frac{GS}{(G+S)}} \left(\frac{S}{G+S}\right) = \frac{K\theta}{2}$$

or $$I_g = \frac{ES}{R\,(G+S) + GS} = \frac{K\theta}{2} \qquad \text{.......}(ii)$$

---

* *For Practice Only.*

Comparing (*i*) and (*ii*), we get

$$(R+G)\,2S = R\,(G+S) + GS$$

or $(R - S)\,G = RS$

or $$\boxed{G = \frac{RS}{R-S}} \qquad \text{.........} \; (iii)$$

If the value of R is very large as compared to S, then $\frac{R}{R-S}$ is nearly equal to unity. Hence

$$\boxed{G \approx S} \qquad \text{.............} \; (iv)$$

Procedure :

1. Draw a diagram showing the scheme of connections as in Fig. 12.1 and make the connections accordingly.

2. Check the connections and show the same to the teacher before passing current.

3. Introduce a high resistance R from the resistance box (R.B.), close the key K_1 and adjust the value of R till the deflection is *within scale* and *maximum*. Note the deflection and the value of the resistance R.

4. Close the key K_2 and adjust the value of the shunt resistance S so that the deflection is reduced *exactly to half the first value*. Note this deflection and the value of the resistance S.

[**Note.** *As the value of S* **increases** *deflection* **increases.**]

5. Repeat the experiment *three* times taking different deflections of the galvanometer.

Observations and Calculations :

S. No.	Resistance R (ohms)	Deflection θ	Shunt Resistance S (ohms)	Half deflection $\left(\frac{\theta}{2}\right)$	Galvanometer Resistance $G = \frac{RS}{R-S}$ (ohms)
1.					
2.					
3.					
4.					

Mean value of G =....ohms.

Precautions :

1. The value of 'R' should be large.

2. To decrease the deflection, the shunt resistance should be decreased and vice-versa.

3. In this method it is assumed that the deflection is proportional to the current. This is possible only in a weston type moving coil galvanometer.

4. The connections must be tight and the ends of connecting wires should be cleaned.

ORAL QUESTIONS

Q. 1. *Why do we use a high resistance box in series with battery in half deflection method ?*

Ans. In order to bring the deflection of the galvanometer within the scale.

Q. 2. *What should be the deflection when we bring the shunt resistance box in circuit without taking out any resistances from it ?*

Ans. The deflection should become zero.

Q. 3. *What formula do we use in this experiment ?*

Ans. $G = \frac{GS}{R - S}$ where R and S are the resistances taken out from high resistance box and shunt resistance box and G is the resistance of the galvanometer.

Q. 4. *What should be the order of deflection in the galvanometer in the first case ?*

Ans. It should be maximum and within the scale, preferably divisible by 2.

□ □

EXPERIMENT 13

To find the resistance of a given galvanometer by Half Deflection Method and to convert it into an ammeter of a given range (0—50 mA).

Apparatus :

A weston type galvanometer, a voltameter, a battery of two or three cells, two resistance boxes, a high resistance rheostat, one-way key, an ammeter (of nearly the same range as given for conversation); connecting wires, sand paper, a metre rod and a screw gauge.

Theory :

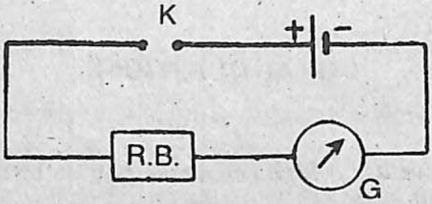


Fig. 13.1. Figure of Merit

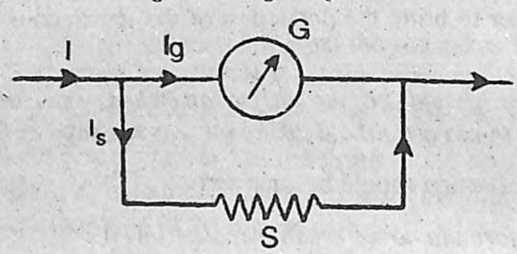


Fig. 13.2 Principle of an ammeter

Fig 13.2 represents a galvanometer of resistance G, in parallel with a shunt of resistance S. The main current I divides itself as shown in the figure. The currents obviously divide themselves in the inverse ratio of their resistance, *i.e.*,

$$\frac{I_s}{I_g} = \frac{G}{S} \qquad \text{........ } (i)$$

or

$$\frac{I_s + I_g}{I_g} = \frac{G + S}{S}$$

or

$$\boxed{\frac{I}{I_g} = \frac{G + S}{S}} \qquad \text{........ } (ii)$$

where G = Galvanometer resistance.

S = Shunt resistance.

I_g = Value of the current required to get a full scale deflection in the galvanometer

I = Value of the current which has to be read by the galvanometer (*i.e.*, its range).

I_s = Current through the shunt resistance.

Thus the current flowing through the galvanometer is a fraction of the main current and is equal to $\left(\frac{S}{S+G}\right)$. The value of 'S' can be so adjusted that the fraction of the main current which the instrument is required to measure, is just sufficient to deflect the galvanometer needle through the whole range of the scale. The shunt resistance from the above equation (*ii*) is given by

$$S = \frac{I_g}{I - I_g} . G \qquad \text{.......... } (iii)$$

It is clear from this formula that if I_g is the current required by the galvanometer coil to produce a full range deflection of the needle, and if we wish to measure a higher current I with its help, we have to insert a shunt resistance S across the galvanometer coil, so that only I_g flows through the coil (thereby still producing the full range deflection), the remaining current being carried through the shunt.

Thus to evaluate S to give a particular range of the current (I) to the galvanometer, we have to determine the *figure of merit* of the galvanometer *i.e.*, we have to know how much current should be sent through the galvanometer in order to produce a deflection of one division on the scale. Thus, if K be the figure of merit of the galvanometer, and 'θ' be the number of divisions on the scale, then

$$\boxed{I_g = K . \theta}$$

The length of the shunt wire can be calculated with the help of the formula

$$\boxed{S = l\rho}$$

where l = length of the shunt wire.

ρ = Resistance per unit length of the shunt wire.

Procedure :

1. *Find the resistance G of the galvanometer by* **Half Deflection Method** *as explained in Experiment No. 12.*

2. To find the figure of merit :

(*i*) Find the e.m.f. of the cell by a voltmeter. See that the positive of a cell is connected to the positive marked terminal of the voltmeter.

(*ii*) Connect the cell, the galvanometer, the resistance box and a key in series as shown in Fig. 13.1. Take out 5,000 ohms plug from the resistance box and make all other plugs tight. Put in the key and adjust the value of R from the resistance box so that a deflection θ, near about 30 divisions is indicated in the galvanometer. Note the deflection θ in the galvanometer and also the value of the resistance R from the resistance box.

(*iii*) Adjust the value of R to get a deflection of about 20 divisions and again note the deflection and the resistance.

(*iv*) Increase the number of the cells to two. Find the e.m.f. and the value of R to get a deflection of about 30 and again about 20 divisions as in the previous step.

3. *To determine shunt resistance and length of the shunt wire :*

(*i*) Calculate the shunt resistance S from the equation

$$\boxed{S = \frac{I_g}{I - I_g} \cdot G}$$

(*ii*) The value of shunt resistance required is usually very small and a resistance box of that range is not available. As a rule such resistances are obtained by selecting wires of a suitable material like copper, constantan, manganin, eureka etc., of a suitable diameter and length. The material and the diameter of a wire can be ascertained from the tables of constants given below :

Table of Resistance of wires of various gauges and material

S.W.G No.	Diameter in mm.	Resistance per metre in ohms		
		Copper	Manganin	Eureka
14	2·03	0·0054	0·131	0·146
16	1·63	0·0083	0·204	0·228
18	1·22	0·0148	0·361	0·405
20	0·914	0·0260	0·645	0·722
22	0·711	0·0435	1·07	1·20

24	0·559	0·070	1·73	1·93
26	0·457	0·105	2·58	2·89
28	0·374	0·155	3·82	4·27
30	0·315	0·222	5·45	6·08
32	0·274	0·293	7·18	8·02
34	0·234	0·404	9·90	11·10
36	0·193	0·590	14·50	16·20

Consult the table of constants given above and find the diameter of a wire, of a suitable material, whose 20 to 30 cm length (*l*) gives the required resistance.

(*iii*) The wires available in the laboratories are usually *not of standard gauges*. Take a wire and measure its diameter accurately at least at 10 different places. Calculate the length '*l*' of the wire, specific resistance of which can be known, from the following formula :

$$\boxed{l = \frac{S\pi r^2}{k}}$$

where k is the *specific resistance of the material of the wire and S is Shunt Resistance.*

(*iv*) Cut a length of the wire 2 cm more than the calculated value '*l*'. Mark in ink, two points one cm from each end. Connect the wire to the two terminals of the galvanometer such that the marked points are *just outside* the terminal screws.

Now the galvanometer in conjunction with this length of shunt wire has been converted into an ammeter of a given range.

4. Verification :

Now set up an electrical circuit as shown in Fig. 13.3.

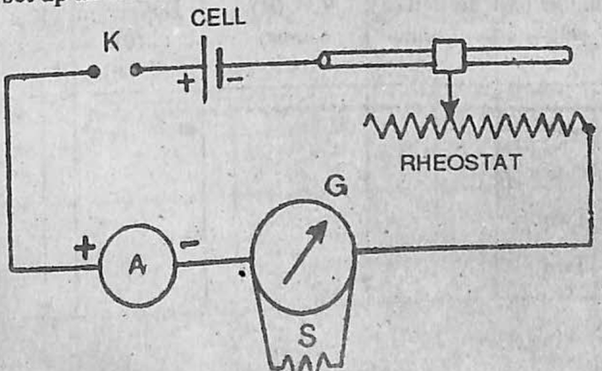


Fig. 13.3. Verification

Connect the cell through a key (K) to an ammeter (A), the converted galvanometer and a Rheostat in series. See that the *positive* of the cell is connected to the *positive* marked terminal of the ammeter (of nearly the same range as the converted galvanometer).

Put the key (K) in position and adjust the resistance from the rheostat so that the galvanometer indicates nearly the maximum deflection. Note the reading on the galvanometer scale and also the corresponding reading on the ammeter. Convert the galvanometer readings to amperes and find the difference, if any, between the readings of the two instruments. This gives the error of the galvanometer reading. Take 6 or 7 readings for difference values of the current and draw a *graph* between the two readings.

Observations and Calculations :

(*i*) Resistance of galvanometer by Half Deflection Method:

S. No.	Resistance R (ohms)	Deflection θ	Shunt Resistance S (ohms)	Half-deflection $\left(\frac{\theta}{2}\right)$	Galvanometer Resistance $G = \frac{RS}{R - S}$ ohms
1.					
2.					
3.					
4.					

Mean value of 'G' =....ohms

(*ii*) Figure of merit :

No.	Number of cells	e.m.f. of the cell (E) (volts)	Resistance in R.B. (R) (ohms)	Deflection (θ) (div.)	Figure of Merit $K = \frac{E}{(R+G)\theta}$
1.	One				
2.	One				
3.	Two				
4.	Two				

Mean value of K = ... ampere per division (*iii*) **Calculation of Shunt :**

Number of divisions on galvanometer scale

$= n =$....

Current for full scale deflection I_g

$= nK =$....A

Range of conversion I $=$ .... A

∴ Shunt Resistance $= S = \dfrac{GI_g}{I - I_g} =$ .....ohms

(*iv*) **To find the Length of Wire :**

Least count of the screw gauge = ...mm

Zero correction =....mm

Observed diameter

(1) ......mm (2) . ...mm (3) ....mm

(4) ....mm (5) ....mm (6) ....mm

Mean observed diameter =......mm

Corrected mean diameter =......mm

Radius of the wire $= r =$....cm

Specific Resistance of the material

$= k =$..... ohm cm

Hence the length of the wire $= l = \dfrac{S\pi r^2}{k} =$ .....cm

where S = shunt resistance

(*v*) **Verification :**

One scale division after conversion =..........A

S. No.	Reading of the shunted galvanometer		Ammeter Reading (I′) in amperes	Error (I — I′) in amperes
	In divisions	In Amperes (I)		
1. 2. 3. 4. 5. 6. 7.				

Result :

The length of the shunt wire of S.W.G.....required to convert the given galvanometer into an ammeter of range.... amperes =.....cm

Precautions and Sources of Error :

(*i*) The cell used should have a constant electromotive force.

(*ii*) The length of the wire used as shunt resistance should not be too small or inconveniently too large.

(*iii*) While connecting the shunt wire across the galvanometer, care should be taken to see that exactly the measured length is in parallel with the instrument.

(*iv*) The resistance box should be a high resistance one and should preferably be of a dial pattern. At no stage of the experiment should the resistance in the box be zero or small, otherwise an excessive current shall flow through the galvanometer or ammeter which will consequently be damaged.

(*v*) The zero reading if any in the instruments should be carefully noted down and accounted for in the calculations.

(*vi*) The ammeter used in the verification part of the experiment should preferably be of the same range as the one which has been prepared with the shunted galvanometer.

(*vii*) The ammeter should always be connected in series in the circuit with its positive marked terminal connected to the positive of the cell.

(*viii*) If an uni-directional galvanometer is used, its positively marked terminal should be connected to the higher potential point of the circuit.

Exercise

Convert the given galvanometer into a milliammeter of range 0-300 milliamps.

ORAL QUESTIONS

Q. 1. *What is an ammeter ?*

Ans. Ammeter is a moving coil galvanometer of which the scale is calibrated to give the value of the current directly in amperes.

Q. 2. *There is then no difference between an ammeter and a galvanometer except the graduations of the scale. Is it not so ?*

Ans. No. There is one essential difference between the two. The resistance of the ammeter is comparatively much lower.

Q. 3. *It is very essential for the ammeter to have a very low resistance? Explain why ?*

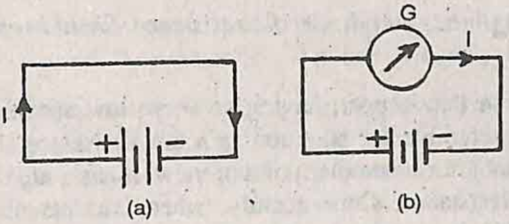


Fig. 13.4

Ans. Yes. It is an indispensable condition. In Fig 13.4 (a) is shown an electric circuit in which a current I is flowing. It is to be measured. For this purpose, a galvanometer G [Fig 13.4 (b)] is inserted. Since the galvanometer coil has an appreciable resistance, the effective resistance of the circuit increases. Consequently the current now flowing through it will be diminished. Let it be I'. The deflection in the galvanometer will consequently correspond to I' and not to the original current I and greater the resistance of the measuring instrument, greater the error ($I—I'$) in the measurement of current. Obviously, the ideal instrument should have zero resistance so that $I = I'$. This is not feasible in practice, hence the next best choice is to make the resistance of the instrument as low as possible.

In addition to this, the voltage drop (IR) across the instrument and the power loss (I^2R) and consequent heat produced in it must, in spite of large currents, be negligible.

All these considerations require that the ammeter should always have a negligibly *low* resistance.

Q. 4. *How is the resistance of the ammeter made low ?*

Ans. The resistance of the instrument is made low by connecting across its terminals (*i.e.*, parallel to the galvanometer coil) a thick strip of very low resistance, usually called a *shunt*. Consequently according to the law of parallel resistances, the effective resistance of the shunted instrument becomes even less than that of the shunt itself.

Q. 5. *Is there any other additional advantage of shunting the instrument ?*

Ans. Yes. Now the instrument can be inserted in a circuit carrying a current which would ordinarily damage the unshunted galvanometer. In this case a major part of the current is conveyed by the shunt and only a safe part is allowed to flow through the coil.

Q. 6. *What is the material of the shunt ?*

Ans. Manganin is usually employed for this purpose.

Q. 7. *Manganin has a high specific resistance. Should copper be more desirable ?*

Ans. It is true that copper, having a very low specific resistance, appears to be preferable for adoption as a low resistance shunt. But its use is objectionable from another point of view. It has a *high temperature coefficient* of resistance. Consequently, when currents of appreciable magnitude shall flow through the copper shunt, its resistance shall undergo a change and thus the *calibration* of the instrument shall be altered. No such difficulty arises in the use of manganin which has a vanishingly small temperature coefficient of resistance.

Q. 8. *How can we have a shunt of low resistance of manganin ?*

Ans. This is accomplished by using several thick strips of manganin in parallel with one another and connecting the combination in parallel with the coil of the galvanometer.

Q. 9. *What is the order of the resistance of the ammeter you are using in your experiment ?*

Ans. Weston type ammeter whose resistance is of the order of 0·01 ohm.

Q. 10. *One thing is puzzling. The main current flowing through an electric circuit does not flow through the ammeter coil, only a very small fraction flows through it. Then how is it that the ammeter reads the main current ?*

Ans. Actually the instrument is *calibrated* by direct comparison with a standard instrument (as for instance with an accurately calibrated potentiometer). The graduations on the dial of the ammeter are marked according to the values given by the potentiometer.

Q. 11. *What precautions do you observe when you insert ammeter in a circuit and why ?*

Ans. An ammeter is employed to measure a current flowing in a circuit, hence the whole current must pass through it. *Thus this instrument is always connected in series with the circuit.*

Secondly, the ammeter is uni-directional instrument. The zero of the scale is at *one end* so that the pointer can be deflected to one side only. *In no case should the deflection occur in the opposite sense.* For this purpose one of the binding terminals is *marked* (+). *The current in the ammeter is always allowed to enter through this terminal i.e.*, the +ve terminal is connected to the *positive* electrode of the battery or cell.

Q. 12. *In a Weston galvanometer the pointer is placed in the middle of the scale. Can not the pointer be put at one end as in the ammeter ?*

Ans. The galvanometer is employed in the laboratory for the detection of electric currents, whose direction may be, as in the experiments of wheatstone bridge, sometimes in one direction and sometimes in the other. Obviously, such a procedure can be adopted only when the zero mark of the scale lies in the centre.

Q. 13. *Can't we have the zero mark of the ammeter scale in the middle? In that case we need not worry about the positive terminal. Is it not so ?*

Ans. We can have zero mark in the middle. There is no difficulty about it. Moreover, we shall have no worry about the choice of terminals. But there is no need. On the other hand there is a *positive disadvantage. In this case we shall be making the range of the ammeter half.*

Q. 14. *What is the range of your ammeter? Give answer according to the range of your instrument.*

Ans. The range is 1 ampere (say).

Q. 15. *Can we make it read 10 amperes ? If so, how ?*

Ans. Yes, By putting a shunt of suitable magnitude, it can be used to read upto 10 amperes.

Q. 16. *Indicate briefly how you can do it ?*

Ans. From the Fig. 13.5 it is clear that out of 10 amperes, 1 ampere should flow through the ammeter for giving full scale deflection and the remaining 9 amperes, should be carried by the new shunt. Now, the currents in the two parallel branches are *inversely* proportional to their resistances. Hence

$$\frac{1}{9} = \frac{S}{G}$$

or $$\boxed{S = \frac{G}{9}}$$

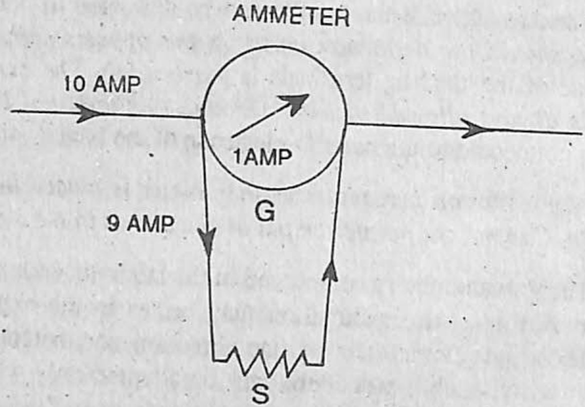


Fig. 13.5

Thus by taking a shunt equal to *one-ninth* the resistance of the ammeter, the range can be increased to 10 amperes.

Q. 17. *What is a milliammeter? What is a miliiampere ?*

Ans. It is also an ammeter which reads current upto 10^{-3}th millionth part of an ampere.

1 milliampere = 10^{-3} ampere
(*m*A)

Q. 18. *What is a microammeter? What is a microampere ?*

Ans. It is also an ammeter which reads current upto 10^{-6}th part of an ampere.

1 microampere = 10^{-6} ampere.
(μA)

Q. 19. *How can you convert an ammeter into a milliammeter?*

Ans. This can be done by *increasing the resistance of the shunt* of the instrument.

Q. 20. *When is the value of shunt resistance greater : (a) for conversion to a range of 3 amperes or (b) for conversion to a range of 30 amperes ?*

Ans. For conversion to a range of 3 amperes.

Q. 21. *Can you use a D.C. ammeter for measuring alternating current ?*

Ans. No. It cannot be done.

Q. 22. *Why not ?*

Ans. D.C. ammeter depends for its action on the magnetic effects of currents, and the direction of the magnetic field produced by the current flowing in the coil depends upon the direction of the current.

In an A.C. the direction of the current changes after each half cycle, so the direction of the field due to the coil, and consequently its direction, shall undergo a change after each cycle. The coil, however, cannot follow the rapid oscillations of the alternating current, hence it will remain undeflected.

Q. 23. *How will you then measure an A.C. ?*

Ans. It can be done by using an *A.C. ammeter or Hot Wire Ammeter.*

Q. 24. *On what principle is the working of A.C. ammeter based ?*

Ans. The working of A.C. ammeter depends upon the heating effect of electric current. According to Joule's Law, heat produced in a current-carrying conductor is proportional to the square of the current. Thus the amount of heat produced due to the passage of electric current in the conductor is independent of the direction of flow of the current.

Q. 25. *Give a brief outline of the Hot wire instrument (or A.C. Ammeter).*

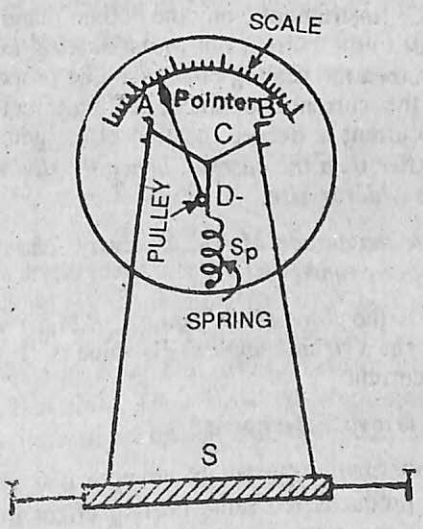


Fig. 13.6. Hot wire instrument (or *A.C. Ammeter*)

Ans. It consists of a platinum iridium wire AB (Fig 13.6) fixed rigidly between the two point A and B. At its middle point C a wire of phosphor bronze is attached. This, in turn, is fastened to a fine silk thread, which passing round a small pulley 'D' is attached to a spring which keeps the whole system taut. 'S' is a low resistance connected in parallel with the wire AB.

When alternating current (A.C.) flows through the wire AB, it gets heated and expands. The sag is taken up by the spring (Sp) and causes the pulley to rotate. A pointer attached to the spindle of the pulley is thereby deflected over a graduated scale which gives the current.

Q. 26. *Can A.C. Ammeter (or Hot wire instrument) be used for measuring direct current (D.C.) ?*

Ans. Yes. It can be used for this purpose.

Q.27. *How can you distinguish at sight between a (D.C.) ammeter and a hot wire (A.C.) ammeter ?*

Ans. This can be easily done by looking simply at the graduated dials of the two instruments. Scale divisions on the D.C. ammeter are all of *equal* size, while those on the dial of a hot wire ammeter are of *unequal* size. In the beginning of the scale the divisions are *smaller* in size and they go on becoming *wider* towards the other end.

Q. 28. *Can you explain the cause of this difference ?*

Ans. Yes. In the case of D.C. ammeter, the current is directly proportional to the deflection produced, hence all the divisions are of equal size.

In the A.C. instrument, on the other hand, the deflection is proportional *not* to the current but to its *square, i.e.*, if the currents be, say, I, 2I, 3I,.....then the heating effect shall be proportional to I^2, $4I^2$, $9I^2$, ... Thus when the current is doubled, heating effect becomes four times, and when the current is trebled, heating effect gets nine times. *Heating effect grows faster than the current, hence the divisions towards the end of the scale are wider in size.*

Q. 29. *If the magnitude of A.C. is always changing, which value is then read by your ammeter ?*

Ans. It reads the *Root Mean Square (R.M.S.)* value of the current, which is known as a *virtual ampere*. Its value is $\frac{1}{\sqrt{2}}$ times the value of the maximum current.

Q.30. *What is a virtual ampere ?*

Ans. An alternating current of strength one virtual ampere is that current which produces the same heating effect in a conductor as the steady current of one ampere will do during the same time.

EXPERIMENT 14

To find the resistance of a given galvanometer by Half Deflection Method and to convert it into a voltmeter of a given range (0—3V).

Apparatus :

A Weston type galvanometer, a voltmeter of 0-3 volts range, a battery of 2 to 3 cells, two resistance boxes, a key, a Rheostat of about 100 ohms resistance, connecting wires and a piece of sand paper.

Theory :

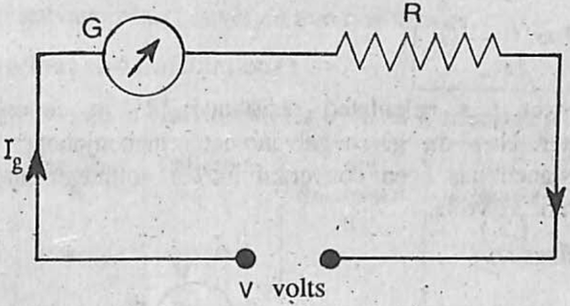


Fig. 14.1. Principle of a Voltmeter

In Fig. 14.1 G is a galvanometer which requires a current, say, I_g to produce a full scale deflection of the pointer. Now we have to read a potential difference of 'V' volts with the help of this galvanometer. It is easy to understand that if we connect the galvanometer directly with V, excessive current shall flow and the coil of the galvanometer shall be burnt out. No current greater than I_g should be allowed to flow through G. Obviously the excessive current can be cut down by inserting a series resistance of proper value so that the requisite current I_g flows through the galvanometer. If this resistance be R, we have from Ohm's Law

$$I_g = \frac{V}{G + R}$$

Hence $$\boxed{R = \frac{V}{I_g} - G} \qquad \text{...}(i)$$

Thus to evaluate the series resistance we have to know the value of I_g. For this purpose we should determine the *figure of merit* of the given galvanometer, *i.e.*, we should know how much current should be sent through the galvanometer in order that a deflection of one division is produced on the graduated scale. Thus if K be the figure of merit of the galvanometer, and *n* be the number of divisions on scale, then

$$\boxed{I_g = Kn} \qquad \text{...}(ii)$$

Procedure :

1. Find the resistance of the galvanometer by Half Deflection Method as explained in **Experiment No. 12.**

2. Find the *figure of merit* of the galvanometer as explained in **Experiment No. 13.**

3. From the above determinations, calculate the value of R, the *series resistance*, with the help of equation

$$\boxed{R = \frac{V}{I_g} - G}$$

4. Connect this calculated resistance 'R' in series with the galvanometer. Now the given galvanometer in conjunction with this series resistance has been converted into a voltmeter and can read voltages upto 'V' volts.

5. **Verification :**

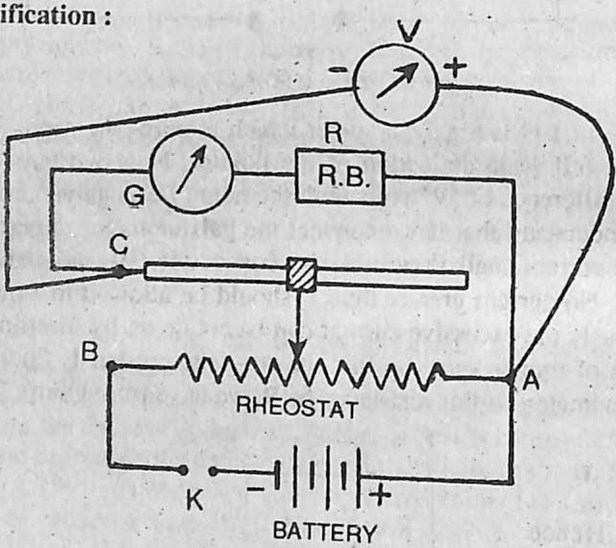


Fig. 14.2. Verification

(*i*) Draw a diagram showing the scheme of connections as in Fig. 14.2.

(*ii*) Connect the battery of 3 cells through a key (K) to the fixed terminals A and B of the Rheostat. Connect the galvanometer through a resistance box (R.B.) between the terminals A and C of the rheostat. Also connect the voltmeter between the same two terminals so that the positive marked terminal is connected at A where the positive of the battery is connected.

(*iii*) Take out the calculated resistance R from the resistance box (R.B.) and keeping the movable contact near A, put in the key K. Note the reading of voltmeter and galvanometer. Convert the galvanometer reading into volts and calculate the error, if any, between the two values.

(*iv*) Move the variable contact of the rheostat and take about *six* such observations lying between 0 and 3 volts and then draw a calibration curve between the two readings of voltmeter and galvanometer converted into a voltmeter.

Observations and Calculations :

(*i*) Resistance of Galvanometer by Half Deflection Method

S. No.	Resistance R (ohms)	Deflection θ(ohms)	Shunt Resistance S	Half deflection $\left(\frac{\theta}{2}\right)$	Galvanometer Resistance $G = \frac{RS}{(R-S)}$ ohms
1.					
2.					
3.					
4.					

Mean value of 'G' =....ohms

(*ii*) Figure of Merit of the Galvanometer

Number of divisions on the galvanometer scale =..................

No.	Number of cells	e.m.f. of the cells (E) (volts)	Resistance in R.B. (R) (ohms)	Deflection (θ) (div.)	Figure of Merit $K = \frac{E}{(R+G)\theta}$
1.	One				
2.	One				
3.	Two				
4.	Two				

Mean value of K = ... ampere/division.

(*iii*) Series Resistance :

Resistance of the galvanometer = G=.... ohms

Number of divisions on the galvanometer

$= n =$ ....

Figure of merit = K = ... ampere/scale division

Current for a full scale deflection = $I_g = nK =$ .....A

Conversion range = V= 3 volts

Resistance 'R' to be placed in series with the galvanometer is given by

$$I_g = \frac{V}{R + G}$$

or $$R = \frac{V}{I_g} - G$$

∴ $$\boxed{R = \frac{3}{I_g} - G} \text{ ohms}$$

(*iv*) Verification :

One scale division after conversion =.....volts

S.No.	Reading of the galvanometer converted into voltmeter		Voltmeter Reading (V′) in volts	Error (V — V′) in volts
	In divisions	In volts (V)		
1.				
2.				
3.				
4.				
5.				
6.				

If there is a large difference between the reading (in volts) as indicated by the galvanometer (converted into the voltmeter) and that given by the standard voltmeter, adjust the value of the resistance (R) in the resistance box (R.B.) till the two readings coincide.

Resistance for correct conversion = ...ohms

Difference =.......ohms

Result :

The series resistance (R) required to convert the given galvanometer into a voltmeter of range 0—3 volts =.... ohms.

Precautions and Sources of Error :

1. The accumulator or battery used in this experiment should be fully charged and should be of a fairly large capacity so that it gives a constant current throughout the experiment.

2. The resistance box should be a high resistance one and should preferably be of dial pattern. At no stage of the experiment should the resistance in the box be zero or small, otherwise an executive current shall flow through the galvanometer which will consequently be damaged.

3. The zero reading in the galvanometer or the voltmeter should be carefully noted down and accounted for in the calculations.

4. The voltmeter used in the verification part of the experiment should preferably be of the same range as the one which has been prepared with the galvanometer.

5. While connecting the series resistance with the galvanometer care should be taken to see that *exactly* the calculated resistance (R) is in series with the instrument.

6. The voltmeter should always be connected in parallel with the circuit with its *positive* marked terminal connected to the positive of the battery.

7. If an uni-directional galvanometer is used, its positively marked terminal should be connected to the higher potential point in the circuit.

Exercise

"Convert a Weston Type of galvanometer into a voltmeter of range 250 volts."

ORAL QUESTIONS

Q. 1. *What is voltmeter ?*

Ans. A voltmeter is a *high resistance* moving coil galvanometer, which is used for the measurement of potential differences in *volts* directly.

Q. 2. *What is the fundamental difference between a voltmeter and an ammeter ?*

Ans. The resistance of the voltmeter is very high while that of the ammeter is very low. The voltmeter is always connected *in parallel* in the circuit whereas an ammeter is always connected *in series.*

Q. 3. *How high and how low? Can you give some idea ?*

Ans. Yes, the resistance of the voltmeter may be of the order of say, 200 ohms while that of an ammeter may be of the order of 0.01 ohm.

Q. 4. *Why is the resistance of a voltmeter kept so high ?*

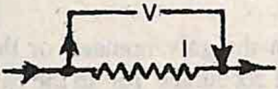


Fig. 14.3 (a)

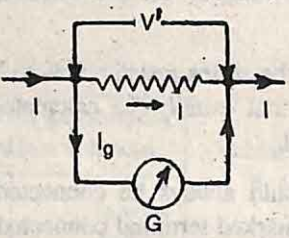


Fig. 14.3 (b)

Ans. In Fig. 14.3 (a) is shown a conductor carrying a current I. The potential difference V at its ends is to be measured. For this purpose, a moving coil galvanometer (voltmeter) G is connected at its two ends Fig. 14.3 (b). It draws a certain current through itself; consequently the current through the conductor is not I but I', where I' is less than I. Thus the potential difference at the ends of the conductor is not 'V' as before but V' where V' is less than V. Consequently the instrument G will resister a deflection proportional to V' and an error equal to $(V—V')$ will be introduced in the measurement of V. *Less the resistance of this instrument, greater is the current drawn by it and consequently greater is the fall in the potential differences measured by it. The error $(V—V')$ will correspondingly be greater. Obviously if we wish to reduce this error we should increase the resistance of the instrument.*

Again the power consumption, $\frac{V^2}{R}$ and consequent heat produced in the instrument shall also be negligibly small when the resistance R of the measuring instrument is as high as possible.

It is for these reasons that the resistance of the voltmeter is kept very high.

Q. 5. *The higher the resistance of the voltmeter, the better it is. So it will be an ideal instrument if the resistance is infinite. Is it not so ?*

Ans. Yes, an instrument with infinite resistance shall really be an ideal one.

Q. 6. *Can your voltmeter have infinite resistance ?*

Ans. No, the resistance of an *electromagnetic* voltmeter can be made very high but can never be infinite. The coil must draw some current however small.

Q. 7. *Do you know of any voltmeter which has an infinite resistance ?*

Ans. Yes, an *electrostatic* voltmeter has an infinite resistance ?

Q. 8. *If electrostatic voltmeters are ideal, why do you not use them in the laboratory for measuring, say the E.M.F. of a cell ?*

Ans. Electrostatic voltmeters are not sufficiently accurate to read low voltages of this order. Hence they do not find a place in the laboratory for daily use.

The useful range of these voltmeters is from *500 volts* upwards to several hundred *kilovolts*.

(*Note* : 1 kilovolt = 1000 volts).

Q. 9. *What is the range of your voltmeter ?*

Ans. It is 5 volts (say)

(Give appropriate answer according to the range of your instrument).

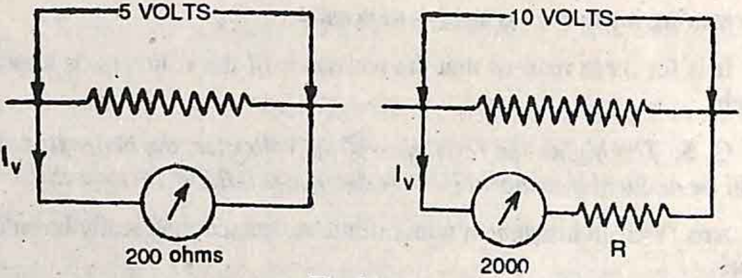
Q. 10. *Can you make it read 10 volts ? How ?*

Ans. From Fig. 14.4 (*a*) it is clear that the current (I_v) drawn by the voltmeter is given by $I_v = \frac{5}{200}$ amp; because 200 ohms is the resistance of the voltmeter (say).

[Resistances are indicated by the makers on the dial].

If we wish to *measure 10 volts with the same instrument Fig. 14.4 (b) we should connect a high resistance (R) in series with it such that*

$$I_v = \frac{5}{200} = \frac{10}{200 + R} \text{ or } R = 200 \text{ ohms.}$$



(a) *Fig. 14.4* (b)

Q. 11. *How can you make your voltmeter read millivolts ?*

Ans. It can be done by suitably cutting down the series resistance.

[*Note* : 1 millivolt = 10^{-3} volt]

Q. 12. *Can you use this instrument (i.e., your D.C. voltmeter) for the measurement of A.C. voltages ?*

Ans. No. It cannot be used for this purpose. The electromagnetic instrument being unidirectional in its action is useless for measuring A.C. voltages. A hot wire instrument *(with a non-inductive high resistance in series with the platinum iridium wire) i.e., A.C. voltmeter* is used for this purpose. A.C. voltmeter would measure potential differences in *virtual volts.*

Q. 13. *A voltmeter is marked 62 ohms per volt and another is marked 1000 ohms per volt. Which one will you prefer ?*

Ans. The one marked with 1000 ohms per volt because the error in the measurement of potential differences by this device will be much less. Also the power consumption and heat produced will be negligibly small.

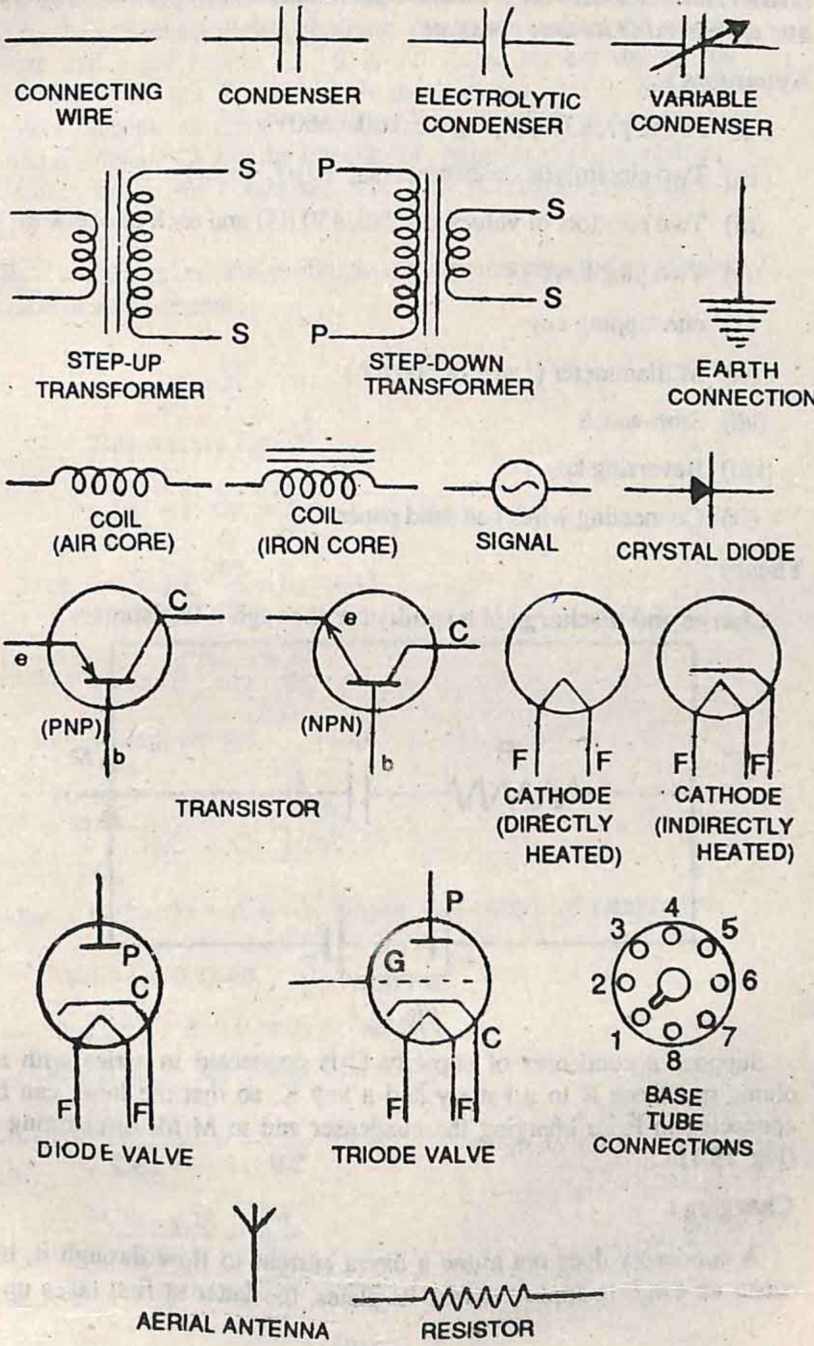
Q. 14. *Why is one terminal of a voltmeter marked positive ?*

Ans. Voltmeter is a unidirectional instrument. The zero of the scale is at one end so that the pointer can be deflected to one side only. In no case should the deflection occur in the opposite sense. For this purpose one of the binding terminals is marked (+) and also the (+) terminal of a voltmeter should be connected to the +ve electrode of a battery or a cell in the circuit.

SOME SYMBOLS

for

The Circuit Components in ELECTRONICS



EXPERIMENT 15

To study the charging and discharging of a capacitor through a resistor, milliammeter (or a sensitive galvanometer) by plotting a graph and to determine its time constant.

Apparatus :

(*i*) Power pack (supplying d.c. 200—300V)

(*ii*) Two electrolytic condensers (say 20 μf, 40 μf)

(*iii*) Two resistors of values say 220, 450 KΩ and each of one watt

(*iv*) Two plug keys

(*v*) one tapping key

(*vi*) Milliammeter (1 mA or 500 μA)

(*vii*) Stop-watch

(*viii*) Reversing key

(*ix*) Connecting wires and sand paper.

Theory :

Charge and discharge of a condenser through a Resistance.

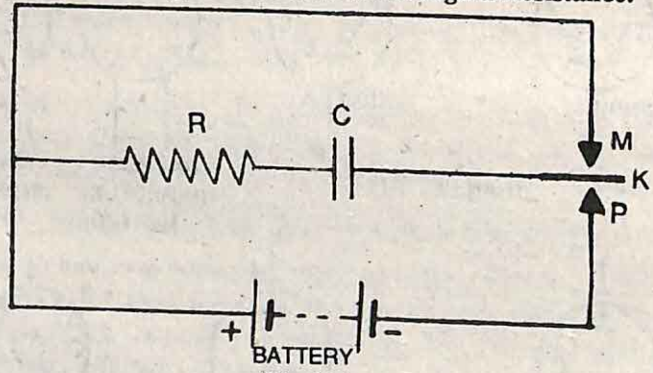


Fig. 15.1

Suppose a condenser of capacity C is connected in series with an ohmic resistance R to a battery and a key K, so that the latter can be connected to P for charging the condenser and to M for discharging it (Fig. 15.1).

Charging :

A condenser does not allow a direct current to flow through it, but when an *e.m.f.* is applied across its plates, the latter at first takes up a small charge and a displacement current is set up in the dielectric between the plates. The battery tries to introduce more and more charge, and the charge already attained by the plates of the condenser, therefore, opposes the introduction of further charge. In other words, a back *e.m.f.* is set up by the condenser during charging. At the same time, the battery gives more and more charge *i.e.*, it is delivering current during the process, which will not flow through the dielectric (it is only the displacement current, as distinct from the other current, which flows through the condenser C), but the quantity of charge given by the battery will be stored up by the condenser. The flow of charge constitutes a varying current.

Let E_0 = *e.m.f.* applied across the circuit. On charging the condenser the equation of *e.m.f.* becomes

$$RI + \frac{Q}{C} = E_0$$

$$\text{But current } I = \frac{dQ}{dt}$$

$$\therefore\ E_0 - R\frac{dQ}{dt} = \frac{Q}{C}$$

or $$RC\frac{dQ}{dt} = E_0C - Q$$

or $$\frac{dQ}{E_0C - Q} = \frac{dt}{RC}$$

Integrating, we get

$$\int_0^Q \frac{dQ}{E_0C - Q} = \int_0^t \frac{dt}{RC}$$

$\therefore\ -\log_e(E_0C - Q) + A = \frac{t}{RC}$ where A is constt. of integration.

When $t=0, Q=0$.

$$\therefore\ -\log_e CE_0 + A = 0 \text{ or } A = \log_e CE_0$$

$$\therefore\ -\log_e(CE_0 - Q) + \log_e CE_0 = \frac{t}{RC}$$

or $$\log_e \frac{(CE_0 - Q)}{CE_0} = -\frac{t}{RC}$$

$$\therefore\ \frac{CE_0 - Q}{CE_0} = e^{\frac{-t}{RC}}$$

or $$Q = CE_0\left(1 - e^{\frac{-t}{RC}}\right)$$

But $CE_0 = Q_0$ (Maximum charge)

$$\therefore \quad Q = Q_0\left(1 - e^{\frac{-t}{RC}}\right) \qquad \text{.........}(i)$$

and potential (E) across the condenser is

$$E = \frac{Q}{C} = \frac{Q_0}{C}\left(1 - e^{\frac{-t}{RC}}\right) = E_0\left(1 - e^{\frac{-t}{RC}}\right) \qquad \text{..........}(ii)$$

$$\text{Also current } I = \frac{dQ}{dt} = \frac{E_0}{R}\, e^{\frac{-t}{RC}} = I_0\, e^{\frac{-t}{RC}} \qquad \text{.........}\ (iii)$$

where $I_0 = \frac{E_0}{R}$ = Maximum current at the beginning of charging.

If t is numerically equal to RC

$$Q = Q_0\left(1 - e^{-1}\right) = Q_0\left(1 - \frac{1}{e}\right) = Q_0\left(1 - \frac{1}{2{\cdot}72}\right)$$

$$= 0{\cdot}638\, Q_0$$

$$\therefore \quad \frac{Q}{Q_0} = 63\% \qquad \text{........}\ (iv)$$

Hence in RC seconds, the charge on the condenser reaches 63% of its final charge Q_0.

The product 'RC' has the dimension of time and is called the *time constant* of the circuit. It is defined as the time taken for a condenser to reach 0·638 of its final charge.

Thus it takes time for the condenser to be charged to its fullest extent.

Discharge of a condenser through resistance :

After charging the condenser, if the key K is connected to M (Fig. 15.1) the condenser is discharged; the expression for discharging.

$$RI + \frac{Q}{C} = 0 \qquad [\therefore E_0 = 0]$$

$$\because \quad \frac{Q}{C} = -RI = -R\frac{dQ}{dt}$$

$$\text{or} \quad \frac{dQ}{Q} = -\frac{1}{CR}\,dt$$

and solving for Q as before, bearing in mind that at $t = 0$, $Q = Q_0$

We get $Q = Q_0\, e^{\frac{-t}{RC}}$ ....(*v*)

and potential across the condenser is

$\frac{Q}{C} = \frac{Q_0}{C} \cdot e^{\frac{-t}{RC}}$ ....(*vi*)

Also $I = I_0\, e^{\frac{-t}{RC}}$ (discharging current) ....(*vii*)

Thus the time taken to discharge a condenser of a few microfarads through a resistance of say, one megohm is a few seconds.

Also $V_R = IR = -E_0\, e^{\frac{-t}{RC}}$ ....(*viii*)

and $V_0 = \frac{Q}{C} = \frac{Q_0}{C}\, e^{\frac{-t}{RC}} = E_0\, e^{\frac{-t}{RC}}$ ....(*ix*)

The *negative* sign in equation (*viii*) shows that V_R (Potential across the resistance R) opposes V_C (Potential across the plates of the condenser C). *The two potentials being equal but opposite.*

Procedure :

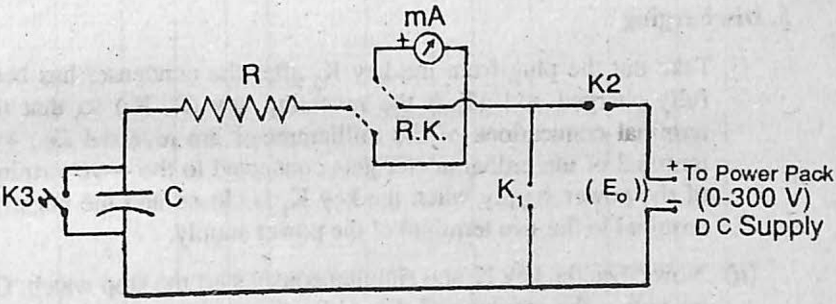


Fig. 15.2. Circuit Diagram

1. Draw the circuit diagram showing the scheme of connections as shown in Fig. 15.2 and then make the electrical connections accordingly. The connections should be clean and tight.

Get the connections approved by the teacher and seek his permission to proceed further.

2. Make the connections in such a way that the *positive* terminal of milliammeter (mA) gets connected to the positive terminal of the power supply when the key K_2 is closed and the negative terminal through the

resistance R to the negative terminal of the power supply as shown in circuit diagram above.

3. Switch on the power supply and wait for about 3-4 minutes till the power supply stabilizes to give constant voltage. Now adjust the knob of the power supply so that it gives a suitable d.c. output voltage (initially small values say 50, 100, 150, 200 V or similar convenient values). This voltage is indicated in the meter of the power supply.

4. Charging :

(*i*) Close the key K_2 and watch the movement of the pointer of the milliammeter. If the movement is too fast to be noted with the stop-watch, replace R or C or both with those having large values. In case the movement is too slow, reduce R or C or both.

(*ii*) After choosing suitable values of R and C, close the key K_2 and start the stop watch simultaneously. Go on noting down the readings of milliammeter after equal intervals of time till the current practically becomes zero. The choice of the suitable time interval depends upon the values of R and C taken. When the milliammeter indicates practically zero current, the charging of the condenser is almost full at the power supply voltage 'E_0'.

5. Discharging :

(*i*) Take out the plug from the key K_2 after the condenser has been fully charged and adjust the reversing key (R. K.) so that the terminal connections of the milliammeter are reversed *i.e.*, +ve terminal of the milliammeter gets connected to the —ve terminal of the power supply when the key K_1 is closed and the negative terminal to the +ve terminal of the power supply.

(*ii*) Now close the key K_1 and simultaneously start the stop watch. Go on noting the readings of the milliammeter regularly after equal intervals of time till the current becomes practically zero.

Note. As the condenser takes very long time to get fully discharged, so before starting next observations, it is discharged by pressing the key K_3. Repeat the above steps for charging and discharging for the same values of R and C.

6. For another set of observations, the above procedure (1 to 5) may be repeated with different values of R and C.

7. Tabulate the observations and draw graphs as shown in Fig. 15.3.

8. Calculate the time constant by multiplying the resistance R *in ohms* by the capacity C *in farads* of the capacitor.

Warning :

The power supply can be a source of danger. Wires connected to it should be well insulated and so placed that they are not likely to be touched accidentally.

Observations :

Least count of the milliammeter = ... *m*A

Zero reading of the milliammeter = ... *m*A

Constant voltage from the power supply (E_0) = ...volt

No. of obs.	Resistance R in		condenser (C) in		Time constant = RC	Time in secs.	Corrected current (I) through the capacitors in *m*A					
							During Charging			During Discharging		
	KΩ	Ω	µ*f*	*f*			(*i*)	(*ii*)	Mean	(*i*)	(*ii*)	Mean
1					(secs)	0 sec						
						.....						
						.....						
						.....						
						.....						
						.....						
						.....						
						.....						
						.....						
2						0 sec						
						.....						
						.....						
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Graphs :

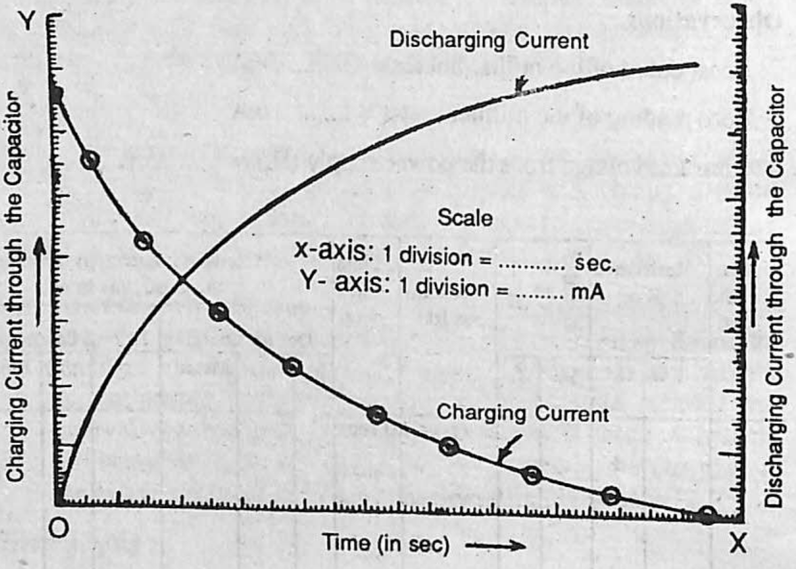

Fig. 15.3. Charging and discharging currents of a condenser.

Result :

(*i*) Time constant of the first capacitor = ...s

Time constant of the second capacitor = ...s

(*ii*) It is clear from the graphs (Fig. 15.3) that the current flow has an *exponential nature* in both the cases of charging and discharging of a capacitor through a resistance.

Precautions :

1. After making connections, get it approved by the teacher and seek his permission to proceed further.

2. Wires connected to the power supply should be well insulated and so placed that they are not likely to be touched accidentally.

3. The connections should be clean and tight.

4. The connecting wire should be straight and not coiled in order to eliminate to effect due to self-induction.

5. Positive terminal of the electrolytic condenser should be connected to the positive terminal of the power supply.

6. The electrolytic condenser chosen should have minimum possible self-leakage.

7. Before starting fresh observations, the condenser should be discharged by pressing the tapping key K_3 connected across it.

8. The terminals of the milliammeter must be reversed while studying the discharge of the condenser.

9. Initially start with small voltages from the power supply and increase it gradually to a value (E_0) which gives a suitable amount of current in the circuit.

Sources of Error :

(*i*) The condenser may not be free from dielectric loss.

(*ii*) The resistances may not be non-inductive.

ORAL QUESTIONS

Q. 1. *What do you mean by the capacity (or capacitance) of a conductor ?*

Ans. It has been found experimentally that the quantity of charge (Q) given to a conductor is directly proportional to its potential (V).

$$Q \propto V$$

or

$$\frac{Q}{V} = \text{constt.} = C.$$

This constant 'C' is called the capacity of the conductor and is defined as the ratio of the charge on the conductor to its potential.

If, however, $V = 1$, then $Q = C$.

Hence, the capacity of a conductor may also be defined as the amount of charge required to raise its potential by unity.

Q. 2. *Upon what factor does the capacity of a conductor depend ?*

Ans. The capacity of a conductor depends upon

(*i*) its *size*, being greater as the size is increased.

(*ii*) the *dielectric constant* of the medium in which the conductor is placed; greater the value of the dielectric constant, greater is the capacity of the conductor.

(*iii*) the *presence of other conductors* in the vicinity of the conductor.

Q. 3. *What is a condenser (or a capacitor)?*

Ans. A condenser (or a capacitor) is a device for storing charge. Basically, it consists of two conducting plates separated by an insulating material called dielectric.

The underlying principle is that the capacity of a charged conductor increases when another conductor is brought near it and more so when the latter is earthed.

Q. 4. *How do you define the capacity of a condenser?*

Ans. The capacity of a condenser is numerically equal to the amount of charge which must be given to the condenser in order to establish unit potential difference between its plates.

Q. 5. *Upon what factors does the capacity of a condenser depend?*

Ans. The capacity of a condenser depends upon three factors :

(*i*) *Area (A) of each plates*; greater the area, greater is the capacity.

(*ii*) *Distance between the plates* (d); less the distance, greater is the capacity.

(*iii*) *Dielectric constant of the medium* (K); greater the value of the dielectric constant, greater is the capacity. For a parallel plate condenser, $C=\frac{KA}{4\pi d}$.

Q. 6. *Define dielectric constant of a substance.*

Ans. Dielectric constant of a substance is the ratio of the capacity of a condenser using that substance as a dielectric to the capacity of the same condenser with air as the dielectric.

Q. 7. *What are the dielectrics often employed in the construction of a condenser?*

Ans. The dielectrics generally used are :

(*i*) Mica,

(*ii*) Paraffined Paper, and

(*iii*) Ceramic dielectrics.

Q. 8. *When are ceramic dielectrics employed?*

Ans. They are used to obtain controlled temperature coefficients, so that changes in capacity due to temperature are minimised.

Q. 9. *What in your opinion, is the best dielectric, and why ?*

Ans. Mica is the best dielectric and used for all good standard condensers. Its dielectric constant is very high (its value varies from 5·7 to 7); hence even for a small thickness of this substance we can have appreciable values of the capacity. Moreover, its insulation does not break even if high potential differences (several kilovolts per mm.) are applied on the coatings of the condenser.

Q. 10. *What types of condensers do you know ?*

Ans. There are three types of condensers :

(*i*) Condensers with air as dielectric.

(*ii*) Condensers with a solid dielectric (Paper condenser; Mica and ceramic condensers).

(*iii*) Electrolytic condensers.

Again, the condensers may be parallel plate, spherical or cylindrical depending upon the shape of their plates.

Q. 11. *What is a paper capacitor ?*

Ans. Paper capacitor consists of a strip of wax paper placed between two strips of tin or aluminium foil which are about 2·5 cm. wide and 2·5 to 4 m. in length. The strips of foil and the waxed paper are then rolled up and encased in a small card board or metal cylinder. This arrangement results in a small physical size but with a large plate area and comparatively large capacitance. Often the plates of aluminium or tin foil are separated by a thin film of paper treated with an oil or a film of plastic material.

Q. 12. *What are Mica and Ceramic condensers ?*

Ans. These condensers are formed by sand-witching mica or ceramic which are dielectric materials between two metal plates.

Q. 13. *What is an Electrolytic condenser ?*

Ans. As the name suggests this condenser utilises the phenomenon of electrolysis for its operation (Fig. 15.4).

It consists of aluminium electrodes dipped in a solution of ammonium borate. Due to the passage of current electrochemical reaction takes place whereby a thin film of ammonium oxide is formed on the positive electrode. This film is highly insulating, non-conducting and serves the purpose of an efficient dielectric. The electrolyte acts merely as an extension of the negative electrode.

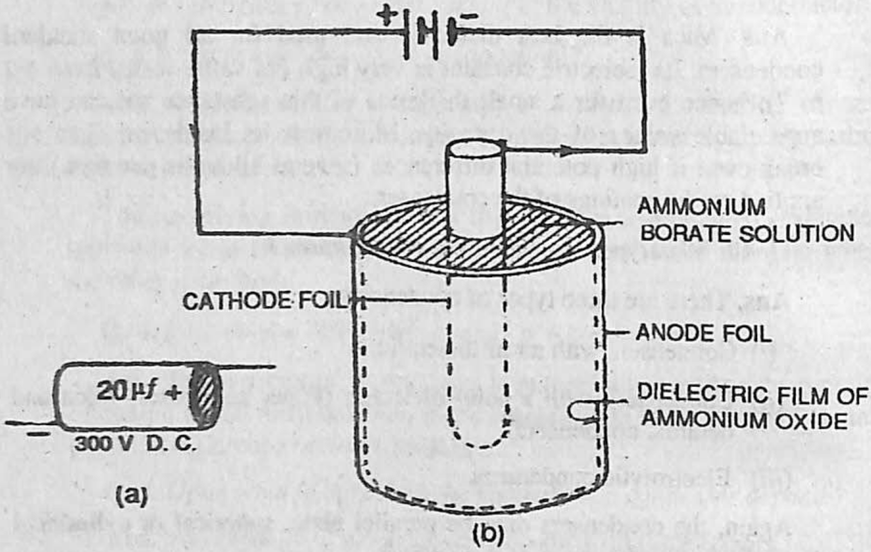

Fig. 15.4. Electrolytic condenser

Q. 14. *What is the merit of such an electrolytic condenser ?*

Ans. In this condenser the thickness of the dielectric is extremely small, consequently fairly large capacities can be manufactured for a smaller size of the condenser. It is for this reason that these condensers are being widely used in radio sets where large spaces are not available for inserting the condensers.

Q. 15. *What precautions will you observe while connecting electrolytic condenser in a circuit ?*

Ans. When electrolytic capacitors are used, care must be taken to connect the terminals from the anode aluminium plate to the positive terminal of the battery, otherwise the oxide film on the anode will break down by the reversal of the electrolytic action. The positive terminal of the capacitor is clearly marked on it.

Q. 16. *Can you name a few appliances where you have seen condensers being used ?*

Ans. In addition to radio and T.V. sets a condenser is also used in Ruhmkorff's induction coil; Wimshurst's machine; electric fans; motors and other electrical and electronic equipments etc.

Q. 17. *A condenser is used in (i) an A.C. circuit, (ii) a D.C. circuit. What will be the difference in its behaviour ?*

Ans. In an A.C. circuit containing a condenser, the current will be constantly flowing ; while in a D.C. circuit there will be a momentary flow of charge, which will stop as soon as the condenser is charged. In this case there will be no continuous flow of current as in an A.C. circuit.

Q. 18. *Can you give any possible reason as to why a condenser does not obstruct the flow of an alternating current ?*

Ans. An electric current is due to the flow of electrons in a circuit. When an alternating E.M.F. is impressed in a circuit, in the first half cycle the electrons are transferred from one coating of the condenser to the other and the condenser is charged. In the next half cycle the E.M.F. changes sign, hence the electrons are re-transferred from the latter coating to the former one, and the condenser is now charged in the reverse direction. This process is repeated after each cycle and the flow of current is continued.

Q. 19. *What is the SI unit in which the capacity is expressed ?*

Ans. The SI unit of capacity is "farad".

Q. 20. *Is there any significance of using this word ?*

Ans. Yes. It is in honour of Michael Faraday who contributed much to the study of dielectric constants.

Q. 21. *Define a farad.*

Ans. The capacity of a condenser is one farad when a charge of one coulomb raises the potential difference between its plates by one volt. It is usually denoted by '*f*.'

Q. 22. *What is electrostatic unit of capacity? How is it related to farad ?*

Ans. The capacity of a conductor is one e.s.u., if a charge of 1 e.s.u. given to it raises its potential by 1 e.s.u. This is the absolute unit of capacity.

$$1 \text{ farad} = \frac{1 \text{ coulomb}}{1 \text{ volt}} = \frac{3 \times 10^9 \text{ e.s.u. of charge}}{\frac{1}{300} \text{ e.s.u. of potential}}$$

$$= 9 \times 10^{11} \text{ e.s.u.}$$

Q. 23. *On a condenser is written 20 μf. What does it mean ? Is this a new unit of capacity ?*

Ans. It means that the capacity of this condenser is 20 microfarad. No, it is not a new unit. It is a millionth part (or 10^{-6}) of a farad. A farad is a much bigger unit, hence this sub-multiple is generally employed in practice.

Q. 24. *Is there any other sub-multiple employed in daily use ?*

Ans. The other sub-multiple often used is a micro-micro farad (μμf); which is again one-millionth part of a microfarad, or 10^{-12} of a farad.

Q. 25. *Suppose you have two condensers. How will you combine them in order to (i) increase, and (ii) decrease their capacity ?*

Ans. (*i*) To increase the capacity the condensers will be connected in parallel, since in this case $C = C_1 + C_2$

(*ii*) To decrease the capacity they will be connected in series in this case

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

Q. 26. *Suppose each condenser has a capacity of 2 μf. What will be their resultant capacity in each case in Q. 25 ?*

Ans. When connecting in parallel, the effective capacity will be 4 μf. When joined in series, it will be 1 μf.

Q. 27. *Can you tell what a microammeter is ?*

Ans. Microammeter is also an ammeter which can measure currents of the order of one-millionth part (or 10^{-6}) of an ampere.

Q. 28. *Suppose in your laboratory a mico-ammeter is not available, then how would you conduct this experiment ?*

Ans. This can be done even with a sensitive, pivoted coil type weston galvanometer. The only thing we need to know about this instrument is that we should know its figure of merit.

Q. 29. *What do you mean by "figure of merit" of a galvanometer ?*

Ans. The figure of merit of a galvanometer is that value of the current which will be required to produce a deflection of one division on the graduated scale.

Q. 30. *On what factors does the rate of charging or discharging of a capacitor depend ?*

Ans. The rate of charging or discharging of a capacitor depends on (*i*) its capacitance (C) (*ii*) some effective resistance (R) in the circuit *i.e.*, depends on the 'RC' on the circuit.

Q. 31. *What is meant by time constant?*

Ans. The product 'RC' has the dimension of time and is called *time constant* of the circuit. It is measured in *second.*

Time constant is the time during which the charge on the capacitor drops to $\frac{1}{e}$th of the initial value.

Q. 32. *What are the extreme values of capacity C of a condenser?*

Ans. The extreme values of capacity (C) are 0 and ∞. It is difficult to achieve these values in practice. For the maximum value we can increase the area (A) and decrease the distance between the plates (*d*) beyond a certain limit. The minimum value is also not zero because of the finite size of the substance.

Q. 33. *Can the capacity of a capacitor be negative?*

Ans. No, since $C = \frac{Q}{V}$ and the sign (+ or —) of Q is the same as that of V so the value of C cannot be negative. It can only be zero.

Q. 34. *When we switch over from the readings of charging to discharging we reverse the terminal connections of the milliammeter—why?*

Ans. This is done because the direction of discharging current is reverse of the charging current.

Q. 35. *What type of capacitor and resistor will you choose for this experiment?*

Ans. I shall be choosing an electrolytic capacitor as its capacity is much larger (few microfarads) and resistor of many kilo-ohm resistance so that the time constant RC is large and hence charging and discharging is slow and measurements becomes easy.

□.□

SECTION — B

8 Experiments are to be performed out of this section.

EXPERIMENT 16

(a) To trace the lines of force due to a bar magnet placed in the magnetic meridian with its north pole pointing to north and to locate the position of the neutral points.

(b) Calculate the magnetic moment and pole strength of the magnet. Given H= 0·30 ×10^{-4} tesla at Delhi.

Apparatus :

Drawing board; sheet of white paper; wax (or brass pins); bar magnet; magnetic compass; knitting steel needle; half metre rod; a piece of chalk and a sharp pencil.

Theory :

The intensity of the field at any point in the field of a bar magnet is due to the combined effect of the magnet and the earth's magnetic field. *Neutral point* is that point where the field due to the magnet is equal and opposite to the magnetic field due to the earth. These two cancel each other and hence the resultant magnetic field intensity at such a point is zero.

When the magnet lies along the magnetic meridian with its north pole towards the geographic north, the neutral points lie on the equatorial line of the magnet.

Let '*d*' be the distance of the neutral point from the centre of the magnet, the intensity at such a point due to magnet is $\frac{\mu_0}{4\pi} \cdot \frac{M}{(d^2+l^2)^{3/2}}$ where M = Magnetic moment of the magnet

$2l$ = length of the magnet

μ_0 = permeability of free space = $4\pi \times 10^{-7}$ Tm/A

At the neutral point, the intensity due to the magnet must be equal to the intensity due to earth's magnet. Therefore

$$H = \frac{\mu_0}{4\pi} \cdot \frac{M}{(d^2+l^2)^{3/2}}$$

Knowing H, *d* and *l*, the magnetic moment can be calculated. Further $M = m \times 2l$

Knowing M and $2l$, the pole strength '*m*' can be calculated.

Procedure :

1. Fix a sheet of white paper with the help of wax or brass pins on the drawing board. Remove the magnet and all other magnetic substances including watch from the vicinity in which you are working. Place the compass needle in the middle of the paper and tap it gently. Rotate the board till the length of the needle is parallel to the shorter edge of the white sheet. Mark the two ends of the stationary needle. Draw a line passing through these two points which indicates the position of the magnetic meridian at the place. Mark this line as N—S line with N towards the geographic north and S towards the geographic south.

Draw the boundary of the board with a piece of chalk so that the board could be brought to its position if by chance disturbed during the experiment.

2. Place the magnet with its axis symmetrical with the meridian with its north pole pointing north and mark its boundary with a fine sharp pencil. *During the experiment the position of the magnet and the board should not be disturbed.*

3. To draw the magnetic lines of force, place the compass needle near the north pole of the magnet. Tap it gently and mark dot against the other end of the stationary nedle. (North pole of the magnet will attract the south pole of the compass needle and hence mark dot against the free north pole of the compass needle). Move the needle forward and set it till its one end (*i.e.*, S-pole) coincides with the dot and mark dot again

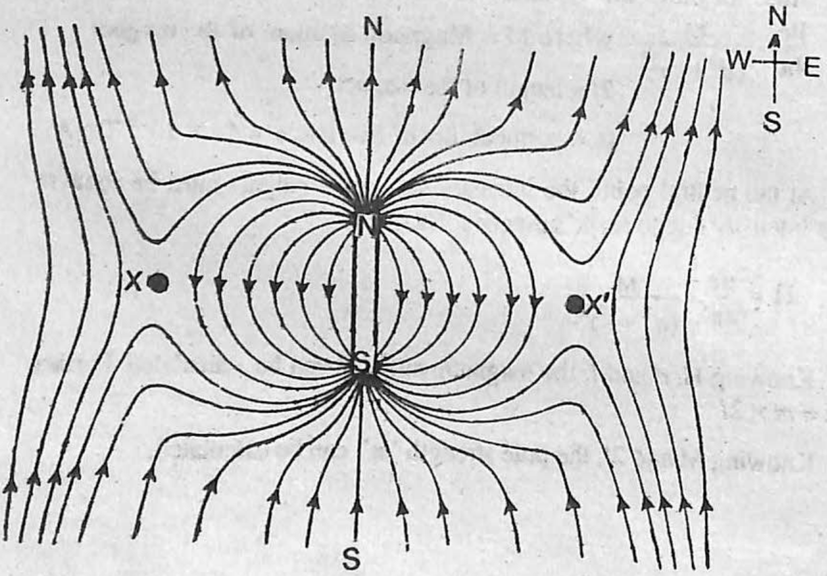

Fig. 16.1

against the other pole. Continue this process till the other end of the magnet *i.e.*, south pole is reached. Now join all these dots by means of a smooth and free hand dotted curve. Mark an arrow indicating the direction of this line of force. [A magnetic line of force starts from a north pole and ends at the south pole of a magnet.]

4. Plot the magnetic lines of force on both the sides of the magnet, indicating the direction by arrow heads from north pole towards the south pole.

5. To trace the lines of force due to the earth's field, mark dots near the East or West Corners of the paper and taking each one of them at the starting point, draw the lines of force in a similar way. These lines of force will give rise to a curvilinear quadrilateral in the neutral region. **More lines should be drawn near the neutral point region.** Through this space neither the lines of force due to the magnet nor due to the earth will pass. Search for a neutral point in this region. Mark the boundary of the compass needle within neutral region. The centre of the circular boundary gives the neutral or null point X. Similarly locate the position of the second neutral point X on the other side of the magnet (Fig. 16.1). The two neutral points will be situated on the equatorial line.

6. Test for Neutral Point :

Place a compass needle with its centre at the neutral point. Bring either a magnet or a magnetised knitting needle near the compass. The magnetic needle will be attracted by it. Now remove the magnet or the needle gently away from the compass without disturbing it. There will be no change in the direction of the magnetic needle at the neutral point. This is because the resultant magnetic field at the neutral point is zero.

7. Measure the distance XX' between the two neutral points which is equal to '2*d*'.

8. Locating the Poles and the Magnetic Length

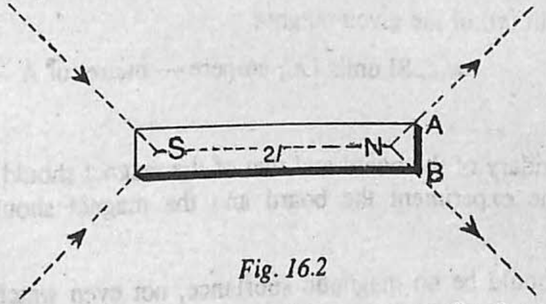

Fig. 16.2

Take the bar magnet and place it on a paper fixed on the drawing board such that its axis is along the magnetic meridian (Fig. 16.2). Make the boundary of the magnet of the paper with a sharp pencil. Choose a point 'A' near the corner of north pole of the magnet and place a compass needle with its one end coinciding with A and trace out a magnetic line of force. Similarly trace out another line of force from the point B at the other corner of the north pole. These two lines of force will meet at the point N when produced backwards. This point 'N' is the position of the north pole of the magnet.

Similarly locate the position of the south pole S. The distance between N and S is called the magnetic length '$2l$'. The magnetic length of a bar magnet is neraly $\frac{7}{8}$ th of its geometrical length.

9. Thus knowing 'd' and '$2l$' calculate the magnetic moment 'M' and the pole strength 'm' of the given magnet in SI units.

Observations :

Distance between the two neutral points XX′

$$= 2d = \text{.....metre}$$

$$\therefore \quad d = \text{.....metre}$$

Effective length, *i.e.*, magnetic length of the magnet = $2l$ = ... metre

Intensity of Earth's horizontal field (H) = $0{\cdot}30 \times 10^{-4}$ tesla (Given).

Calculations :

$$\text{Magnetic Moment} = \text{M} = 0{\cdot}3 \times 10^{-4} \times \frac{4\pi}{\mu_0} \cdot (d^2 + l^2)^{3/2}$$

$$= \text{...............} \ \text{a} — \text{m}^2$$

$$\text{Pole strength} = m = \frac{\text{M}}{2l} = \text{.......} \quad \text{A} — \text{m}$$

Result :

Magnetic moment (M) of the given magnet

=......SI units *i.e.*, ampere — metre² (or A — m²)

Pole strength (m) of the given magnet

= .....SI units *i.e.*, ampere — metre (or A — m)

Precautions :

1. The boundary of the board and that of the magnet should be drawn and during the experiment the board and the magnet should not be disturbed.

2. There should be no magnetic substance, not even watch near the board throughout the experiment.

3. The compass needle should be gently tapped each time to avoid the sticking.

4. The directions of the lines of force should be indicated by arrow-heads.

5. Each neutral point should be well enclosed by lines of forces and time should not be wasted in drawing up necessary large number of lines of force away from the neutral points.

6. The paper should never be fixed with the help of drawing pins of iron.

Sources of Error :

1. The compass needle may not be completely free to move.
2. Presence of some iron bodies.
3. N-S line may not be marked correctly (magnetic meridian).
4. Inequality of poles of the bar magnet.

ORAL QUESTIONS

(Same as in Expt. 17).

□ □

EXPERIMENT 17

(a) To trace the lines of force due to a bar magnet placed in the magnetic meridian with its north pole pointing south and locate the position of neutral points.

(b) To calculate the magnetic moment and the pole strength of the magnet; give $H = 0{\cdot}3 \times 10^{-4}$ tesla at Delhi.

Apparatus :

Drawing board; sheet of white paper; wax or brass pins; bar magnet; magnetic compass; knitting iron needle; half metre rod; a piece of chalk and a sharp pencil.

Theory :

When the magnet is placed with its N-pole towards the Earth's south, the two neutral points in this position lie on the *axial line* each equidistant 'd' from the middle point of the magnet on either side of the magnet and the intensity at either neutral points is given by :

$$F = H = \frac{\mu_0}{4\pi} \cdot \frac{2Md}{(d^2 - l^2)^2}$$ where M and $2l$ are the magnetic moment and length of the magnet, H = Intensity of the Earth's field

$= 0{\cdot}30 \times 10^{-4}$ tesla and $\mu_o = 4\pi \times 10^{-7}$ Tm/A

known as the permeability of free space.

Since $M = m \times 2l$.

$\therefore m = \frac{M}{2l}$ where m = pole strength of the magnet.

Procedure :

1. The magnet should be placed on a drawing board as explained in the procedure of the Experiment 16. However, in this case the north pole N of the magnet should face the geographical south on the magnetic meridian. (The N-S line should be parallel to the longer edge of the white sheet). Mark the boundary of the board with a piece of chalk and that of the magnet with a sharp pencil. *During the experiment the position of the magnet and the board should not be disturbed.*

2. Plot the magnetic lines of force of the magnet and due to the earth's field as explained in the procedure of the Experiment 16. While drawing lines due to the earth's field, mark dots near the north and south corners of the paper and take each of them as the starting point. Locate the position of the neutral points on both the sides of the magnet on its axial line.

3. Test the neutral points accurately as explained in Experiment 16.

4. Locate the North (N) and South (S) poles of the bar magnet and measure its effective length (21) as explained in Experiment 16. Also measure the distance XX between the two neutral points which is '2*d*'.

5. Calculate the magnetic moment 'M' and the pole strength '*m*' as explained in the theory above.

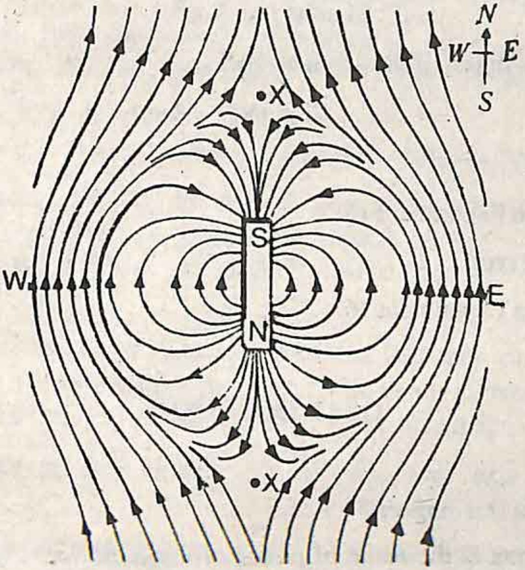

Fig. 17.1

Observations :

Distance between the two neutral points XX = 2*d*=..... metre

∴ *d* =.....metre

Effective length of the magnet = 2*l* =.... metre

∴ *l* = ...metre

Intensity of the Earth's horizontal field H

= 0·30 × 10^{-4} ampere/metre (or T) (given)

Calculation :

(*i*) Magnetic moment 'M' of the magnet

$$= 0{\cdot}30 \times 10^{-4} \frac{(d^2 - l^2)^2}{2d} \frac{4\pi}{\mu_0}$$

$$= \ldots\ldots\ldots\ldots\ldots\ldots \text{SI units}$$

(*ii*) $$\text{pole strength } `m' = \frac{M}{2l} = \ldots\ldots \text{SI units}$$

Result :

Magnetic moment 'M' of the given magnet

= ..... SI units *i.e.*, A-m^2

Pole strength (m) of the given magnet

= .... SI units *i.e.*, A-m

Precautions :

Same as in Experiment 16.

Sources of Error :

Same as in Experiment 16.

ORAL QUESTIONS

Q. 1. *What is a magnet ?*

Ans. Magnet is the name of pieces of magnetic rocks discovered in Magnesia in Asia Minor. The magnetic rock or Magnetite or lode stone is simply an oxide of iron (Fe_3O_4) and occurs in many countries such as U.S.A., Norway, Sweden, Scandinavia, etc. Magnet has the power of attracting iron.

Q. 2. *What is magnetism ?*

Ans. The power of the magnet attracting iron is called magnetism.

Q. 3. *What are the chief properties of a magnet ?*

Ans. (*a*) Attractive property,

(*b*) Directive property,

(*c*) Magnetising property.

Q. 4. *What are magnetic and non-magnetic substances ?*

Ans. Those substances which can be magnetised are called magnetic substances *e.g.*, steel iron, nickel, cobalt, etc.

Those substances which cannot be magnetised are known as non-magnetic substances *e.g.*, brass, copper, etc.

Q. 5. *What are paramagnetic, ferromagnetic and diamagnetic substances ?*

Ans. *Paramagnetic* : Substances which are attracted in a magnetic field, *e.g.*, aluminium, platinum, chromium, oxygen, manganese etc.

Ferromagnetic : Substances which are attracted strongly in a magnetic field, *e.g.*, iron, cobalt, nickel, steel, and their alloys.

Diamagnetic : Substances which are repelled in a magnetic field, *e.g.*, copper, bismuth, mercury, antimony, gold, water, alcohol, air and hydrogen.

Q. 6. *What is an artificial magnet ? What is its advantage ?*

Ans. A magnet obtained by artificial means is called an artificial magnet, *e.g.*, small pieces of iron, when suitably rubbed with a lode stone acquires the directive and attractive properties and behaves like natural magnets.

The main advantage of artificial magnet is that they can be made much stronger than the natural magnets and also of any convenient shape and size, *e.g.*, bar magnet, magnetic needle, horse shoe magnet etc.

Q. 7. *What do you understand by temporary and permanent magnets ?*

Ans. Those magnets which can retain the power of magnetisation for a long time are known as *permanent* magnets, *e.g.*, magnets of cobalt, tungsten, steel and certain alloys.

Those magnets, which become very strong magnets quickly and at the same time lose the power quickly after the magnetising agency is removed are called *temporary* magnets, *e.g.*, electromagnets made of soft iron.

Q. 8. *What are the poles of a magnet ?*

Ans. The poles of a magnet are the points (or regions) which show the maximum magnetic property.

Q. 9. *Define (a) unit pole, (b) magnetic axis, and (c) effective length.*

Ans. (*a*) *Unit pole* ; In SI system, it is that pole which repels a similar and equal pole with a force of 10^{-7} newton when placed in air at a distance of 1 m from it.

(*b*) *Magnetic axis*. The straight line joining the poles of a magnet is called magnetic axis.

(*c*) *Effective length.* Effective length or magnetic length is the distance between the two poles.

Q. 10. *Define: (a) magnetic meridian, (b) magnetic moment, (c) neutral line or equatorial line.*

Ans. (*a*) *Magnetic meridian.* It is a vertical plane passing through the magnetic axis of a freely suspended magnet at a place.

(*b*) *Magnetic moment.* It is the moment of the couple acting on a freely suspended magnet placed at right angles to a unit uniform field of unit intensity. Its C.G.S. unit is *dyne-cm* and *weber metre* or *ampere-metre*^{2} is its SI unit. It is a *vector* quantity and numerically it is equal to the product of pole strength and magnetic length [$M = m \times 2l$].

(*c*) *Equatorial line.* It is a straight line perpendicular to the magnetic axis through its middle point.

Q. 11. *Define (a) magnetic field, (b) uniform field.*

Ans. (*a*) *Magnetic field.* It is the area round about a magnet within which its influence can be felt.

(*b*) *Uniform field.* A uniform field is that in which the magnetic intensity is the same everywhere both in magnitude and direction. The field due to the earth over a small area is a uniform field.

Q. 12. *Are the poles situated exactly at the ends of a magnet ?*

Ans. No, the poles are not situated exactly at the ends.

Q. 13. *At what point of the magnet is the force of attraction (a) maximum, (b) minimum ?*

Ans. The force of attraction is maximum at the poles and minimum at the neutral point.

Q. 14. *Where does a central point lie in a magnet ?*

Ans. At the centre of the magnet through which neutral line passes.

Q. 15. *Can there be a single pole in a magnet? If not, why ?*

Ans. No, we cannot have a single pole. According to molecular theory, the molecules of a magnetic substance are complete magnets in themselves and in the process of magnetisation they get arranged end to end. That is why we cannot have a single pole.

Q. 16. *How will you show that the poles of a magnet are of equal strength ?*

Ans. If we suspend a magnet freely it sets itself in the magnetic meridian. As the magnet has no translatory motion in the north-south direction, it shows that the two forces acting on the magnet are equal. Thus the poles are of equal strength.

Q. 17. *Define: (a) Pole strength, (b) Magnetic line of force, (c) Magnetic Intensity at a point.*

Ans. *Pole strength.* It is the force which the given pole exerts on a unit north pole placed at a distance of 1 metre from it in air. Its C.G.S. unit is *weber*. Its SI unit is *ampere-metre*.

Magnetic line of force. It is a path (straight or curved) along which a unit north pole will move if free to do so. The tangent at any point of line of force gives the direction of the resultant intensity of the field at the point.

Magnetic Intensity at a point in a magnetic field is defined as the force experienced by a unit north pole placed at that point and the direction of the field is the direction in which the unit north pole will begin to move if free to do so. Its SI unit is *tesla* (T) or *ampere/metre*.

Q. 18. *What is intensity of magnetisation ? How is it related to the pole strength ?*

Ans. The magnetic moment per unit volume is called *Intensity of magnetisation* (I).

$$I = \frac{M}{V} = \frac{m \times 2l}{a \times 2l} = \frac{M}{a}.$$ where a is the area.

Thus it is also defined as pole strength per unit area.

Q. 19. *Why do the lines of force not intersect each other ?*

Ans. If two lines of force intersect each other, it means that there will be two values of magnetic field intensities which is impossible. Therefore two lines of force cannot intersect each other.

Q. 20. *What is the effect of heating, hammering and rough handling the magnet ?*

Ans. The magnet loses its magnetism in all cases.

Q.21. *What is a Curie Point ?*

Ans. As we heat a magnet, it loses its magnetisation. The temperature at which it completely loses its magnetisation is called *Curie Point* or its *Critical Temperature.*

Q. 22. *What will be the effect on magnetic moment if*

(a) the magnet is halved length-wise ?

(b) it is halved breadth-wise ?

(c) it is fixed vertically in the earth ?

(d) holes are drilled in it ?

Ans. (*a*) Magnetic moment is halved as length is reduced.

(*b*) Magnetic moment is reduced due to decrease in pole strength.

(*c*) No effect.

(*d*) No effect.

Q. 23. *What are keepers ? What is their function ?*

Ans. If a magnet is placed alone, it loses its magnetising power. In order to avoid this, we place two magnets side by side with a piece of wood in between them and their poles in opposite direction. Two soft iron pieces are placed at the two ends. These are called *keepers*.

Q. 24. *What are the practical uses of a magnet ?*

Ans. (*i*) Bar magnets are used in tangent and Astatic galvanometres.

(*ii*) Horse-shoe magnets are used in ammeters, voltmeters and moving coil galvanometers.

(*iii*) Compass needles are used in finding the north-south direction and to trace the lines of force for a magnetic field.

(*iv*) Mariner's compass is used by sailors in steering ships in right direction.

(*v*) Electromagnets are used in telegraphy, telephone, electric motor, dynamos, cranes, etc.

Q. 25. *What is a neutral point ?*

Ans. It is a point where the magnetic field of a magnet is completely neutralised by the horizontal component of earth's magnetic field.

Q. 26. *What is a null point ?*

Ans. It is a point where the magnetic field due to one magnet is neutralised due to the other. Here the magnetic field due to earth still remains.

Q. 27. *Where will be the neutral point if a magnet is placed in the magnetic meridian ?*

(i) with its north pole pointing earth's north ?

(ii) with its north pole pointing earth's south ?

Ans. (*i*) The neutral point will be on the equatorial line.

(*ii*) The neutral point will be on the axial line.

Q. 28. *What is the material of which permanent magnets are made ?*

Ans. Ordinarily permanent magnets are made of steel. But high quality magnets are made of an alloy of aluminium, nickel and cobalt. These are called *Alnicos.*

Q. 29. *Why does a compass needle suddenly reverse in direction as it croses the neutral point ?*

Ans. Because at the neutral point the direction of the two magnetic fields is in opposite sides. As the two fields are equal, we get a neutral point. So on crossing the neutral point, the magnetic field is in opposite directions, so the needle suddenly reverses in direction.

Q. 30. *Can we locate a neutral point at the poles of the Earth by placing a magnet on the board in a horizontal plane ?*

Ans. No; it is not possible. The value of the horizontal component of the Earth's field is zero at the poles and field due to the magnet cannot be neutralised.

Q. 31. *How is the neutral point tested ?*

Ans. Neutral point it tested by using a soft iron piece near the compass needle placed at that point. The needle will remain stationary in any direction in which it is set by soft iron piece.

Q. 32. *How will you define Intensity of magnetic field in terms of its lines of force ?*

Ans. It is defined as the number of lines of force passing through unit area surrounding that point placed normally to the lines of force. A pole of unit strength gives 4π lines of force.

Q. 33. *Are the magnetic lines of force real ?*

Ans. No, they are imaginary. These are only graphic representations of the direction of magnetic intensity.

Q. 34. *Why is the compass needle tapped gently at the neutral point ?*

Ans. Because near the neutral point the field acting on the needle is very weak and not be able to overcome the force due to friction at the pivot.

Q. 35. *Why do we not use a big needle ?*

Ans. Because the magnetic field is not uniform everywhere.

Q. 36. *What is the direction of lines of force in the magnet?*

Ans. These are from south pole to north pole inside the magnet.

Q. 37. *Where will be the neutral points if the Earth's magnetic field vanishes?*

Ans. Nowhere. Because there will be no magnetic field to neutralize the field due to magnet.

Q. 38. *Where will the neutral points be when*

(i) North pole of the magnet is towards Earth's East ?

(ii) North pole of the magnet is towards Earth's West ?

Ans. (*i*) On North-west and South-east direction.

(*ii*) On North-east and South-west direction.

Q. 39. *Can a magnet has poles of unequal strength ?*

Ans. No, poles of a magnet can never be of unequal strength.

Q. 40. *State Coulomb's Law ?*

Ans. The force of attraction or repulsion between the two poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them.

$$F = \frac{\mu_0}{4\pi} \quad \frac{m_1 m_2}{r^2}$$

where $\mu_0 = 4\pi \times 10^{-7}$ T-m/A and is known as permeability of free space.

Q. 41. *Is there any fixed direction in which a magnetic needle will point when kept at the neutral points of the magnetic field ?*

Ans. No, it can point in any direction as at the neutral point the resultant magnetic field intensity is zero.

Q. 42. *Which is a better conductor of lines of force: Air, Copper or Iron?*

Ans. Iron.

Q. 43. *In what respects does the gravitational field resemble or differ from a magnetic field ?*

Ans. Gravitational and magnetic fields of the earth are present side by side. It is by virtue of gravitational field of the earth that pendulum hangs vertically and vibrates about a mean position when displaced. By virtue of the magnetic field, the compass needle always points in the magnetic meridian and oscillates like a pendulum, when disturbed about its position of rest. The formulas for times of vibration are also analogus, *i.e.*,

$$t = 2\pi\sqrt{\frac{l}{g}} \text{ and } t = 2\pi\sqrt{\frac{I}{MH}}$$

The important differences is that the direction of the gravitational field is always vertical while a magnetic field may have any direction.

Q. 44. *Does a compass needle correctly point towards true north of the Earth ?*

Ans. No, when a compass needle is mounted freely about a horizontal axis and is placed in the magnetic meridian (*i.e.*, parallel to the earth's magnetic lines of force), it does not generally come to rest in a horizontal position. Usually it dips down at some angle with the horizontal direction called angle of dip. Also the magnetic axis and the polar geographic axis do not coincide as shown in Fig. 17.2.

Q. 45. *A magnet is hidden in a wooden box. How will you find its direction and poles without opening the box ?*

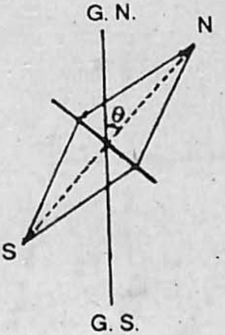

Fig. 17.2

Ans. Place a light magnetic needle on the top of the box. It will set itself parallel to the direction of the hidden magnet. Since opposite poles attract each other, the N-pole of the needle will be towards the S-pole of the hidden magnet and vice versa.

Q. 46. *If you magnetise an iron bar by passing current in a coil wound over it, state the rule by which you can judge the polarity at the two ends of the bar ?*

Ans. Look at the coil wound over the iron bar. If the current is flowing *anti-clockwise* in the face towards you, that end of the bar will be N-pole and if the direction is clockwise, that end will be S-pole and the other will be N-pole.

Q. 47. *Why do iron pillars and posts get slightly magnetised ?*

Ans. This is due to the fact that earth behaves as a huge magnet with its N-pole towards the geographic south and its S-pole towards the geographical north. The posts and pillars made of iron, therefore, get magnetised under the *inductive* action of this huge magnet. In induction *opposite* pole is induced on the nearest end and similar pole is induced on the farther end.

□□

EXPERIMENT 18

(a) To plot the magnetic field of a straight conductor carrying steady current and earth together.

(b) To calculate the value of the steady current. Horizontal component of earth's field (H) at Delhi = $0{\cdot}30 \times 10^{-4}$ ampere/metre

Apparatus :

A large rectangular framework with a covered copper wire passing several times round the frame so as to multiply the magnetic effect of the current; a small accumulator; drawing board; drawing white paper; compass needle; one way key; wax (or brass pins); knitting steel needle; a piece of chalk; a sharp pencil and a half-metre rod.

Theory :

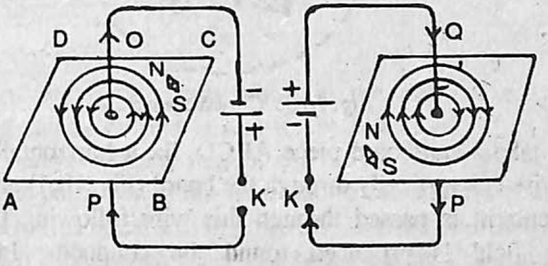

Fig. 18.1. The direction of the magnetic field round a straight conductor carrying current

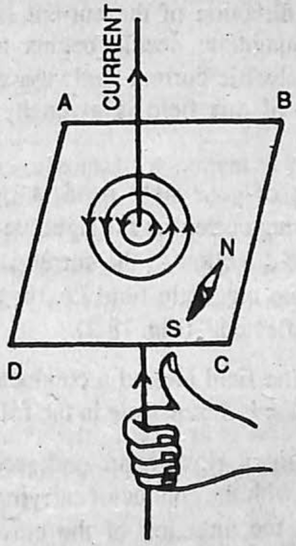

Fig. 18.2. Right hand rule for determining the direction of the magnetic field round a conductor carrying current

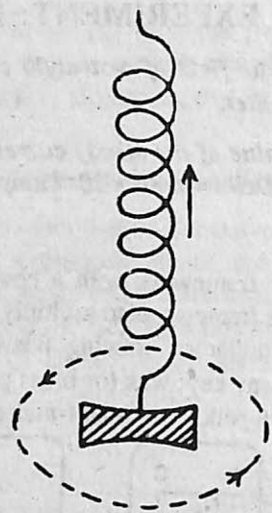

Fig. 18.3. Cork Screw Rule

If we take a cardboard piece ABCD, fix it horizontally, pass a thick copper wire PQ vertically through the board (Fig. 18.1) and then a strong electric current is passed through this wire following from P to Q, a magnetic field is produced round the conductor PQ in a plane perpendicular to the plane of the conductor PQ carrying current. The N-pole of a magnetic needle placed anywhere near the conductor tends to move in the anticlockwise direction.

If, however, the direction of the current is reversed (Fig. 18.1), the north pole of the magnetic needle begins to point in the clockwise direction. Thus an electric current is always associated with a magnetic field. The direction of this field is given by *Right Hand Rule* stated below :

"Hold the thumb of your right hand at right angles to the fingers. Grasp the wire carrying current in the right hand so that the thumb points along the wire in the direction of the current; the fingers will then point in the direction of the magnetic field *i.e.*, in the direction in which the north pole will be deflected." (Fig. 18.2).

The direction of the field around a conductor can also be determined with the help of the *Cork Screw Rule* in the following way :

"Imagine an ordinary right hand cork screw to be lying with its direction coinciding with the conductor carrying current and to be twisted so that it travels in the direction of the current; then the direction in which the thumb rotates gives the direction of the lines of force (Fig. 18.3), *i.e.*, the direction in which the north-pole tends to move round the wire."

The *magnitude* of the magnetic field $\vec{B}$ produced in vacuum at a distance *r* from an *infinitely long straight conductor* carrying a current I is given by

$$\boxed{\vec{B}=\frac{\mu_0 I}{2\pi r}}$$

When the current I is expressed in *ampere* and the distance *r* in *metre*, the magnetic field B is in *tesla* (symbol T). Here μ_0 is the permeability of vacuum and is exactly equal to $4\pi \times 10^{-7}$ Tm/A.

If *n* is the number of wires down the side used, each wire carrying the same steady current I, then

$$\boxed{\vec{B}=\frac{\mu_0 nI}{2\pi r}}$$

The intensity of the field at any point in the field of a straight conductor carrying steady current is due to the combined effect of the straight conductor carrying steady current and the earth's magnetic field. *Neutral point* is that point where the field due to the straight conductor carrying steady current is equal and opposite to the magnetic field due to the earth. These two cancel each other and hence the resultant magnetic field intensity at such a point is zero.

Let '*r*' be the distance of the neutral point from the wire carrying steady current and if H is the horizontal component of the earth's magnetic field, then at the neutral point,

$$\boxed{\frac{\mu_0 nI}{2\pi r}=H}$$

Thus knowing I and *r*, the horizontal component of earth's field H can be determined or knowing *r* and H, the value of the steady current I can be determined. *(It is convenient to arrange for the wire to be vertical and, ignoring the vertical component of the earth's field since this has no effect on a horizontal needle, to trace lines of magnetic force in a horizontal plane.)*

Procedure :

1. Place the rectangular frame with the vertical sides close to the edge of the table and arrange the horizontal drawing board so that it rests securely on the table (Fig.18.4).

Fix a sheet of white paper with the help of wax or brass pins on the drawing board. Remove all magnetic substances including watch from the vicinity in which you are working.

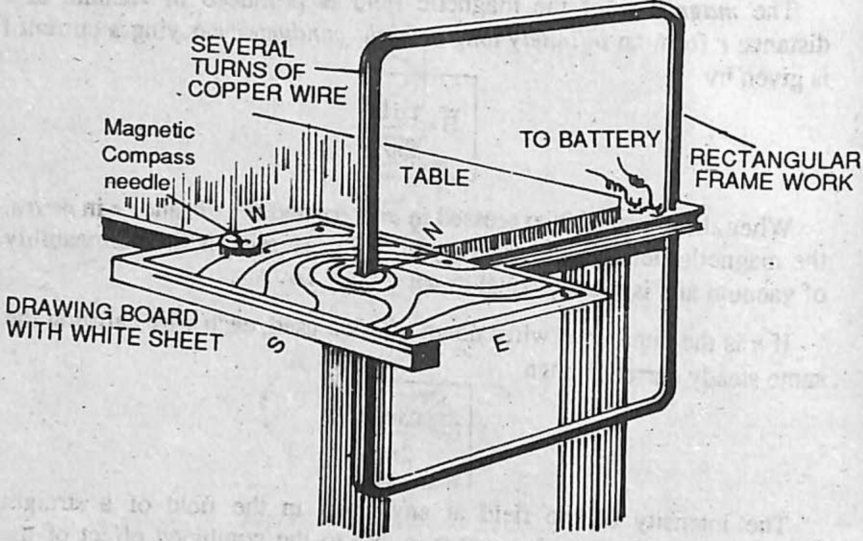

Fig. 18.4. Field of Straight Current

Connect one end of the wire on the rectangular frame to one terminal of a small accumulator, the other terminal to a key and then to the other end of the wire.

2. Trace the magnetic lines of force due to the combined fields of the straight conductor *i.e.*, vertical side carrying current and the earth's field when the current is flowing either downwards or upwards with the help of a compass needle as explained in the procedure of the Experiment 16. *Pay special attention to the lines of force*: (*i*) close to the straight conductor, and (*ii*) near the 'neutral' point.

3. Locate the position of the neutral point and test it accurately as explained in Experiment 16.

4. Having found the position of the neutral point as accurately as possible, measure the distance 'r' from this point to the straight wire carrying steady current.

Observations and Calculations :

Number of turns of the copper wire round the frame = n =....

Distance of the neutral point from the straight conductor carrying current = r =...... m

Intensity of the earth's horizontal field = H = $0{\cdot}30 \times 10^{-4}$ A/m (Given).

Hence, $$\frac{\mu_0 n I}{2\pi r} = H = 0{\cdot}30 \times 10^{-4}$$

or $$\frac{4\pi \times 10^{-7} \times n \times I}{2\pi r} = 0{\cdot}30 \times 10^{-4}$$

∴ $$I = 0{\cdot}15 \times 10^{3} \times \frac{r}{n} \text{ amperes} = \text{.......A}$$

Hence putting the values of *r* and *n* in the above expression, the value of the steady current I in amperes can be determined.

Result :

The value of the steady current I = ...A

Precautions:

1. There should be no other magnet or magnetic substance in the neighbourhood of the rectangular frame, nor there should be any stray wires carrying current close to it.
2. The current must be the same for each turn of the wire.
3. The straight conductor carrying current must be mounted in a *vertical position* with its plane *perpendicular* to the plane of the horizontal drawing board.
4. The compass needle should be gently tapped each time to avoid the sticking.
5. The direction of the lines of force should be indicated by arrow-heads.
6. Neutral point should be well enclosed by lines of force.
7. The paper should not be fixed with the help of drawing pins of iron.

Sources of Error :

1. The compass needle may not be completely free to move.
2. The plane of the straight conductor (wire) carrying current may not be vertical to the plane of the drawing board.
3. The current in the straight conductor may not be steady.
4. Presence of some magnetic substances in the neighbourhood of the straight conductor carrying current.

ORAL QUESTIONS

[Same as in Experiment 17. In addition read the following.]

Q. 1. *What happens when a steady current is passed through a straight conductor held vertically?*

Ans. It behaves like a magnet and produces a magnetic field around it in a plane *at right angles* to the plane of the straight conductor.

Q. 2. *How will you determine the direction of the magnetic lines of force in such a magnetic field?*

Ans. Right-Hand Rule or Cork Screw Rule (See theory explained earlier)

Q. 3. *How does the magnitude of the magnetic field produced by the straight conductor carrying steady current depend upon (i) the strength of the current, and (ii) the distance?*

Ans. (*i*) Magnitude of the magnetic field $\left|\vec{B}\right| \alpha$ current (I)

(*ii*) $\left|\vec{B}\right| \propto \frac{1}{r}$

Q. 4. *What is the S.I. unit of magnetic field?*

Ans. tesla (Symbol T).

□ □

EXPERIMENT 19

(a) To determine the reduction factor of a tangent galvanometer using a Copper Voltameter.

(Given e.c.e. of copper = 0·000329 g/coulomb)

(b) To determine H using tangent galvanometer and Copper Voltameter.

Apparatus :

Tangent galvanometer; a copper voltameter; four copper plates; a battery of 4 to 5 cells; a rheostat; one way key; Reversing key; balance; weight box; spirit level; stop-watch; connecting wires and a piece of sand paper.

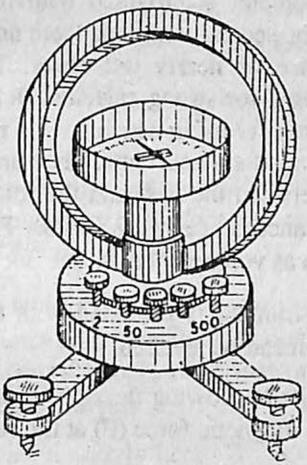

Fig. 19.1. Tangent galvanometer

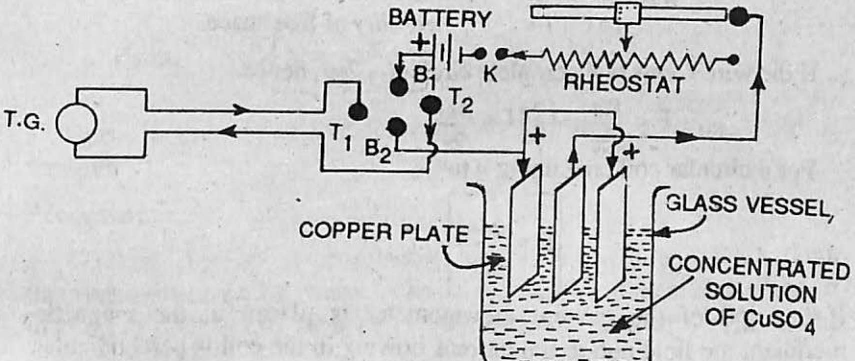

Fig. 19.2.

Theory :

The tangent galvanometer (Fig. 19.1) consists essentially of a small magnetic needle pivoted at the centre of a circular coil of many turns of insulated copper wire, the plane of the coil being vertical. The needle is small and the radius of the coil large, so that the magnetic field in that region round about the centre of the coil where the needle moves, can be taken as uniform. The deflection of the needle is read with the help of a long aluminium pointer attached at right angles to the needle and moving over a graduated circular scale. To protect the needle-pointer system from draughts, it is placed in a non-magnetic box with a glass cover (magnetometer box). To avoid errors due to parallax in reading deflection, the base of the box is provided with a plane mirror.

The tangent galvanometer is provided with four binding terminals. Between the first and the second terminals there are two turns of the coil, which have a resistance of nearly 0·2 ohms. This is known as the ammeter coil and is used for strong currents. Between the first and the third terminals there are fifty turns which have a resistance of nearly 1.1 ohms and are used for moderate currents. They are sometimes known as galvanometer coils. Between the first and the fourth terminals there are 500 turns, whose resistance is nearly 2·25 ohms. These are used for weak currents and are known as voltmeter coils.

The base of the instrument is provided with three levelling screws, with the help of which it can be levelled.

If a current of i units be flowing through 'l' length of wire bent into an arc of 'r' radius, the magnetic force (F) at the centre of the arc is given by

$$F = \frac{\mu_0}{4\pi} \frac{il}{r^2}.$$

where $\mu_0 = 4\pi \times 10^{-7}$ weber/ampere metre or Tm/A known as *permeability* of free space.

If the wire forms one complete circle, $l = 2\pi r$, hence

$$F = \frac{\mu_0}{4\pi} \cdot \frac{i 2\pi r}{r^2} = \frac{\mu_0 i}{2r}$$

For a circular coil containing n turns

$$\boxed{F = \frac{\mu_0 n i}{2r}}$$

If the coil of the tangent galvanometer is placed in the magnetic meridian, the field due to the current flowing in the coil is perpendicular to H, the horizontal component of earth's magnetic field, and consequently the needle placed at the centre of the coil will undergo a deflection θ given by the Tangent Law

$$F = H \tan\theta \text{ where } H = 0{\cdot}32 \times 10^{-4} \text{ weber}/m^2 \text{ or T or A/m}$$

$$= 0{\cdot}32 \text{ gauss}$$

or

$$\frac{\mu_0 n i}{2.r} = H \tan\theta$$

Since $\mu_0 = 4\pi \times 10^{-7}\ Tm/A$

Hence

$$\boxed{i = \frac{10^7\, rH}{2\pi n} . \tan\theta = K \tan\theta}$$

where K is the *reduction factor* of the tangent galvanometer.

If θ = 45°; $\tan\theta = 1$ and

$$\boxed{i = K}$$

Thus the reduction factor of a tangent galvanometer is that current which, when flowing through its coil placed in the magnetic meridian, produces a deflection of 45° in the needle.

The unit of reduction factor is *ampere*. If the same current *i*, which is flowing in the galvanometer coil, also flows through a copper volt meter for *t* seconds, the mass (*m*) of copper deposited on the cathode is given by the Faraday's Law of electrolysis

$\boxed{m = iZt}$ where Z is the electro-chemical equivalent e.c.e of copper.

Thus $i = \frac{m}{Zt} = K. \tan\theta$

Hence

$$\boxed{K = \frac{m}{Z.t. \tan\theta}}$$

Thus in this experiment the voltameter is being used as a current measure.

Procedure:

1. Clean the four copper plates with nitric acid and wash them thoroughly in running water. Dry one of the plates and clean it thoroughly with a fine sand paper. Wash it and let it dry. This is the experimental plate.

2. Draw a circuit diagram showing the scheme of connections as in Fig. 19.2.

3. Remove the insulation from the ends of copper wires and clean their tips with sand paper. Remove the plug from the one way key K and connect the battery, the key, the rheostat, the remaining three plates placed in the copper voltameter to the bottom terminals B_1 and B_2 of the reversing key in series as shown in Fig. 19.2. The negative of the battery should be connected to the central copper plate and the outer two plates should be connected together and then connected to the positive of the battery.

Place the tangent galvanometer *at a distance from the rest of the apparatus* and connect the terminals containing the two turn coil to the top terminals T_1 and T_2 of the reversing key by long parallel wires so that they cancel each other's magnetic field.

4. **Set the tangent galvanometer as explained below :**

(*i*) Remove all magnetic substances from the proximity of the galvanometer.

(*ii*) Set the plane of the coil vertical by adjusting the levelling screws at the base. When it is so the glass top of the box containing the scale will become horizontal. Test by a spirit level placed in various directions on the glass top.

(*iii*) Turn the coil till it is parallel to the magnetic needle *i.e.*, place the eye above the coil, and rotate it till the coil, the needle and its image in the mirror all lie in the vertical plane. Thus the plane of the coil is set in the magnetic meridian.

(*iv*) Tap the box containing the needle gently to ensure smooth working of the needle. Place the eye such that the pointer *just* covers its own image in the mirror at the bottom of the scale and turn the box till the ends of the pointer stand at zero-zero of the scale. Test by tapping the box again.

5. Put the plug in the key K and adjust the value of the current so that the galvanometer gives a deflection nearly equal to 45^0. Reverse the direction of the current and again note the direction.

(The tangent galvanometer is most sensitive when the deflection is 45°. But in no case the deflection should be less than 30^0 or more than 60^0).

6. Weigh the experimental plate accurately. Replace the central plate by the weighed experimental copper plate. Put in the key K and start the stop-watch. Reverse the current after every five minutes and note the deflection by reading both ends of the pointer. Stop the stop-watch after about 30 minutes and at the same time take out the key K. Note the time taken.

7. Take out the experimental cathode plate, *rinse it immediately in dilute sulphuric acid* and wash it thoroughly in running water. Dry it and again find its weight accurately.

Observations :

Mass of the copper plate before the deposit = m_1 = ... g

Time (minutes)	Deflection of the pointer for				Mean deflection (θ)	tan θ
	Direct current		Reverse current			
	one end	other end	one end	other end		
0						
5						
10						
15						
20						
..						
..						
..						
..						
..						

Number of turns used = n =........

Time for which current was passed = t =.... minutes

=....seconds

Mass of the cathode plate after the deposit

= m_2 = ...g

e.c.e. of copper (Z) given = 0·000329 g/coulomb

Calculations :

(*a*) **Reduction factor :**

Mass of copper ions deposited (m) = $m_2 - m_1$ = ...g = ...kg

Now $K=\frac{m}{Z.t \tan\theta}=$....A

(*b*) **Value of H :**

Diameter of the coil = ... *cm* =......*m*

Radius of the coil (r) = ... *cm* =......*m*

Number of turns (n) =....

Since, $K=\frac{10^7 rH}{2\pi n}$ $\therefore$ $H=\frac{2\pi nK}{10^7 r}$

= .... tesla = ... gauss

Result:

(*a*) The reduction factor of the tangent galvanometer for two turns of the coil =.... A

(*b*) The Value of H =..... gauss =........... tesla

Precautions:

(*i*) The magnetometer box should be carefully levelled so that the magnetic needle moves freely in a horizontal plane.

(*ii*) For the validity of the tangent law in this case it is essential that the galvanometer coil is set in the magnetic meridian.

(*iii*) The tangent galvanometer should be placed at a place where there are no magnetic materials, current carrying conductors etc., in its neighbourhood. The rheostat should also be placed at a safe distance from it.

(*iv*) The copper plate on which the deposit has to be made should be scrupulously clean. Its surface should not be touched by hand, otherwise it will be rendered greasy, and the deposit will not adhere properly and evenly.

(*v*) The copper plate should be accurately weighed as the accuracy of the result mainly depends on the measurement of the mass of copper deposited.

(*vi*) The strength of the current should be kept constant throughout the duration of the experiment. The deflection of the galvanometer should, therefore, be kept constant with the help of the rheostat.

(*vii*) As far as possible, the deflection should be kept as nearly equal to 45^0 as possible, since under this circumstance the accuracy in measurement is at a maximum.

(*viii*) To avoid the error due to ex-centricity of the pivot, both ends of the pointer should be read, and to avoid the error due to parallax in reading the deflection, use should be made of the plane mirror attached to the base of the magnetometer box.

(*ix*) In order to avoid error due to any want of accurate setting of the plane of the coil in the magnetic meridian, readings of the deflection should be recorded both for direct and reverse current.

(*x*) To avoid oxidation of fine deposit of copper to copper oxide, the cathode plate should immediately be dipped in water, washed and then dried.

(*xi*) For a good deposit of copper on the plate, the current strength should lie between 1 A and 2 A. With a weaker current a long time should be needed for getting a deposit-sufficient for accurate weighing. On the other hand if the current is too strong, a very large area of the plate has to be dipped in the solution to get a firm deposit.

(As a general rule, for each ampere of current flowing through the solution, the total area of the cathode plate dipped should be 50 cm^2.)

Sources of Error :

1. The coil may not be exactly circular and the needle may not be exactly at its centre.

2. The plane of the coil may not be exactly in the magnetic meridian.

3. The magnetic needle is not very small so that it does not move in a uniform magnetic field at the centre, hence the tangent law is not accurately obeyed.

4. The friction at the pivot may not be totally absent.

5. The scale and pointer method for measuring deflections is not susceptible of great accuracy.

ORAL QUESTIONS

(See Expt. 11).

□ □

*EXPERIMENT 20

To find the focal length of a concave mirror by Parallax Method using one needle and hence determine its radius of curvature.

Apparatus :

Optical bench; two uprights; one needle; concave mirror and a knitting needle; spherometer and a glass plate.

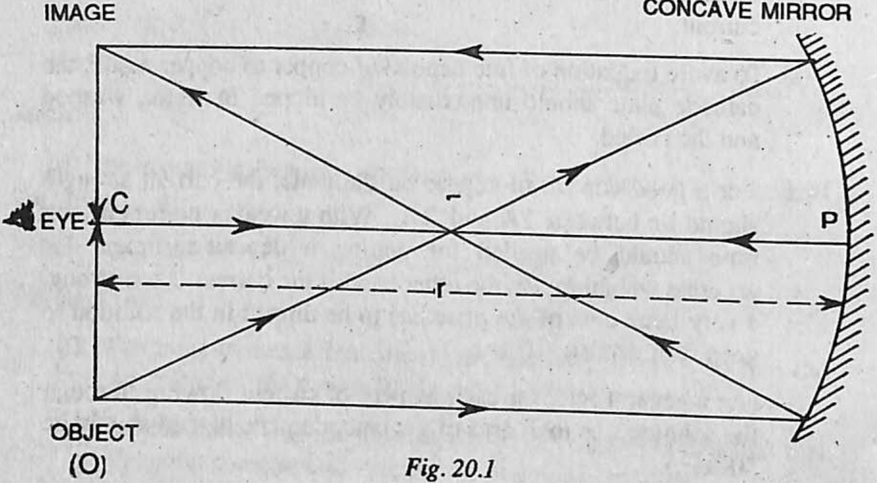

Fig. 20.1

Theory :

If an object (O) is placed at the centre of curvature (C) of a concave mirror (Fig. 20.1), the image (I) of this object formed by the concave mirror is real, of the same size : inverted and is also formed at the centre of curvature. The distance between the centre of curvature of the mirror (C) and its pole (P) is '*r*', the radius of curvature. The focal length (*f*) of the concave mirror is given by the relation

$$\boxed{f = \frac{r}{2}}\ .$$

Procedure :

1. Hold the concave mirror in front of a distant bright object such as a building or a tree. Obtain its sharp image on a screen (wall or a page of a notebook) by changing the distance of the mirror from the screen. Measure the distance of the screen from the mirror. This gives the *rough focal length* of the concave mirror.

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* For practice only.

2. Put two uprights on the optical bench, one holding the concave mirror and the other holding the needle. Adjust their heights so that centre of the mirror and the tip of the needle lie at the same level.

3. Measure the length of a knitting needle with a metre rod. Hold the knitting needle in between the two uprights so that its one end touches the centre of the mirror and its other end touches the tip of the needle. Read the distance between the two uprights on the scale. Find the index correction.

4. Place the needle at a distance twice the rough focal length from the mirror. See for the inverted image of the needle in the mirror. *Do not keep the eye close to the needle as the image may not be clear*. Adjust the height of the needle, so that the tip of the needle just coincides with the tip of its image. *See that they do not overlap*. Remove the parallax between the needle and its image.

5. **Removal of a Parallax :**

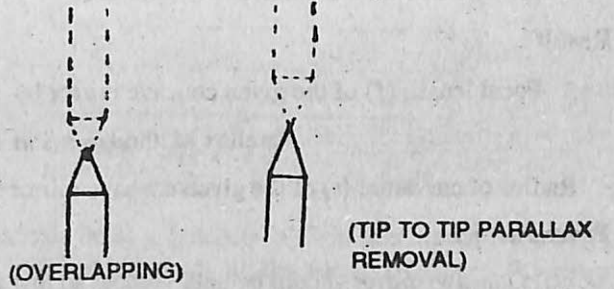


Fig. 20.2

Move the needle sideways, keeping the eye behind the needle. See that tip of the needle coincides with the tip of its image in the centre of the mirror. Move the eye side-ways. Relative shift is produced between the needle and the image. By moving the needle backward and forward along the principal axis of the mirror, get a position where there is no parallax between the needle and its image.

6. Note these positions of the mirror and the needle uprights on the scale.

7. Take five sets of observations by changing the position of the mirror.

Observations and Calculations :

Rough focal length of the concave mirror = ... *cm*

Actual length of the knitting needle = x = ... *cm*

Observed distance between the mirror and the needle

$= y =$ .... *cm*

$\therefore$ Index correction $= x - y = \pm$ .... *cm*

S.No.	Position of upright		Distance between mirror and needle		Focal length $f = \frac{d}{2}$ *cm*
	Mirror	Needle	Observed	Corrected (d)	
1.					
2.					
3.					
4.					
5.					

Mean focal length of the mirror = f = ... *cm*

Result :

Focal length (f) of the given concave mirror by

Parallax Method = ...*cm*

Radius of curvature (r) of the given concave mirror $= 2f =$ ...... *cm*

Precautions :

(*i*) Concave mirror should be held vertical so that its principal axis is parallel to the optical bench.

(*ii*) Tip of the needle should lie on the principal axis of the mirror.

(*iii*) Index correction must be found and applied.

(*iv*) The uprights should be perpendicular to the scale.

(*v*) Eye should be kept at a distance of more than 30 *cm* from the needle.

(*vi*) Tip to tip parallax between the needle and its image should be removed.

ORAL QUESTIONS

(Same as in Experiment 21).

EXPERIMENT 21

To find the value of image distance v for different values of object distance u in case of a concave mirror and hence find the focal length f by plotting of graphs between u and v and $\frac{1}{u}$ and $\frac{1}{v}$

OR

To find the focal length of a concave mirror by u-v method using two pins graphically or otherwise.

Apparatus :

An optical bench with three uprights; concave mirror; two needles; a knitting needle and a metre rod.

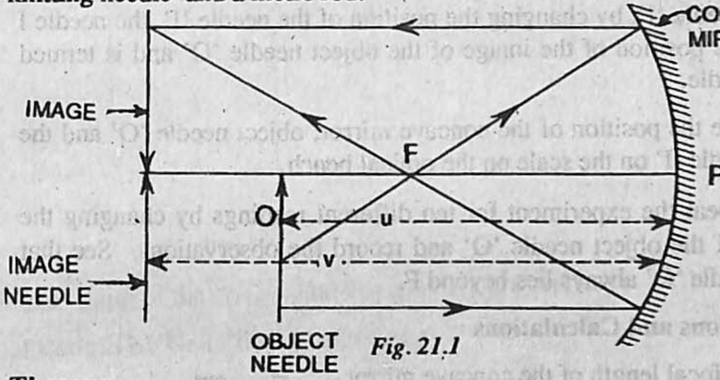


Fig. 21.1

Theory :

Let the object needle be at a distance '*u*' from the mirror (Fig. 21.1). Position of image is found by removing the parallax between the image of the first needle and a second needle. Let '*v*' be the distance of the image from the mirror. Focal length (*f*) of the mirror is related with *u* and *v* by the following equations :

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

or

$$\boxed{f = \frac{uv}{u+v}}$$

Procedure :

1. Find the rough focal length as explained in Experiment 20.

2. Place two uprights on the optical bench one holding the concave mirror and the other holding a needle. Mark the upright holding the

needle as 'O'. Find the index correction between the mirror and the object needle O.

Remove the upright holding the object needle O and place another upright holding the second needle. Mark it as 'I'. Find the index correction between the concave mirror and the image needle 'I'.

3. Place the object needle 'O' between the mirror and the image needle 'I' in such a way that the object needle 'O' lies between focus F and the centre of curvature C of the concave mirror and the image needle 'I' lies beyond 'C'.

4. Attach a piece of paper to the tip of the object needle 'O' so that its image can be distinguished from the image of the needle 'I'.

Remove tip to tip parallax between the image of the object needle 'O' and the needle 'I', by changing the position of the needle 'I', the needle I locates the position of the image of the object needle 'O' and is termed image needle.

5. Note the position of the concave mirror; object needle 'O' and the image needle 'I' on the scale on the optical bench.

6. Repeat the experiment for ten different readings by changing the position of the object needle 'O' and record the observations. See that object needle 'O' always lies beyond F.

Observations and Calculations :

Rough focal length of the concave mirror = ... *cm*

Actutal length of knitting needle = x = ... *cm*

Observed length of knitting needle between 'O' and the mirror = y

= ..... *cm*

Observed length of knitting needle between 'I' and the mirror = z

= ..... *cm*

Index correction for 'u' $= \pm (x - y) = \pm$ .... *cm*

Index correction for 'v' $= \pm (x - z) = \pm$ ..... *cm*

S. No.	Position of			Distance between Mirror and Object Needle (O)		Distance between Mirror and Image Needle (I)		Focal Length $f=\frac{uv}{u+v}$ in cm
	Mirror	Object Needle (O)	Image Needle (I)	Observed	Corrected 'u' in cm	Observed	Corrected 'v' in cm	
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								

Mean $f=$ .....*cm*

Result from Calculations :

Focal length of the concave mirror (by Parallax Method) = ...*cm*

Focal Length by Graphical Methods :

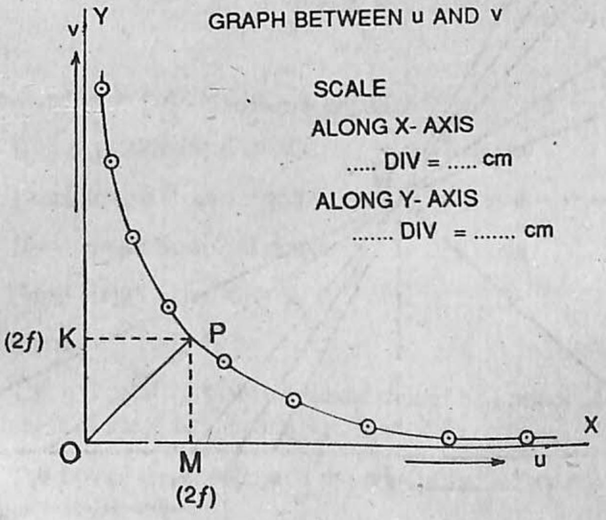


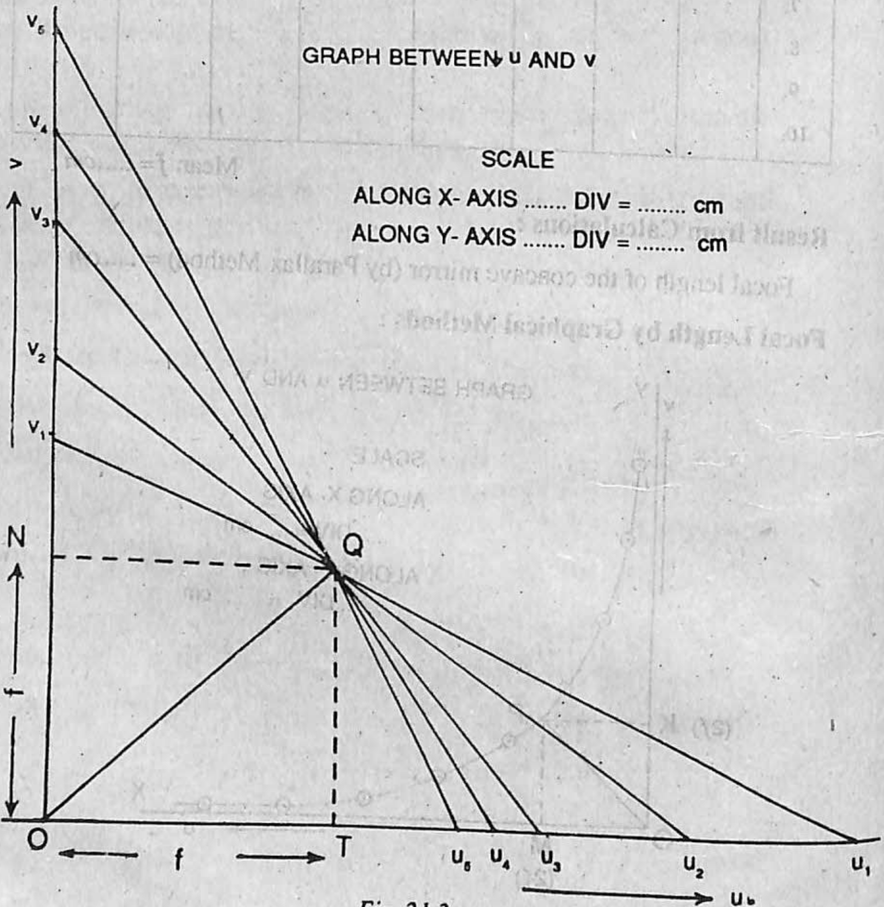
Fig. 21.2

Method No. 1 :

Select proper scale (same scale) to represent *u* along the x-axis and *v* along the y-axis. Plot the points and draw the curve joining these points. This should come out a *rectangular hyperbola* (Fig. 21.2). Draw a line making an angle of 45° with the x-axis. It cuts the curve at the point P. Draw PM and PK perpendiculars on the axes. Note the value of OK or OM. This gives 2*f* where *f* is the focal length of the concave mirror. Half of this will give the focal length of the concave mirror.

Method No. 2 :

Select proper scale (same scale) to represent *u* along the x-axis and *v* along the y-axis. Draw lines joining u_1, v_1; u_2, v_2; u_3, v_3; etc. These intersect at the point Q (Fig. 21.3). Draw perpendiculars QT and QN. Read the value of ON or OT. This will give directly '*f*', the focal length of the concave mirror.



GRAPH BETWEEN u AND v

SCALE

ALONG X- AXIS .... DIV = ... cm

ALONG Y- AXIS .... DIV = ... cm

Fig. 21.3

Method No. 3 :

Select proper scale (same scale) to represent $\frac{1}{u}$ along the x-axis and $\frac{1}{v}$ along the y-axis. Plot the points and join these by the line AB (Fig. 21.4). This will cut the axis at 45°. Measure OA or OB. Then

$$f = \frac{1}{OA} \text{ or } \frac{1}{OB}$$

where f is the focal length of the concave mirror.

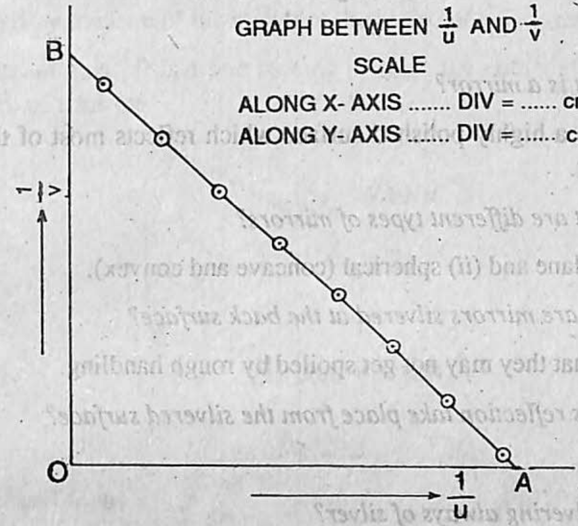


Fig. 21.4

Results :

The focal length of the concave mirror comes out

(1) By calculation focal length = ... *cm*

(2) Focal length from 1st graph = ... *cm*

(3) Focal length from 2nd graph = ... *cm*

(4) Focal length from 3rd graph = ... *cm*

Precautions :

1. The principal axis of the mirror should be horizontal and parallel to the length of the optical bench, *i.e.*, scale.

2. The tips of the needles and the pole of the mirror should be at the same horizontal level.

3. Tip to tip parallax should be removed between the needle I and the image of the needle 'O'.

4. The object and the image needles should not be interchanged for different sets of observations.

5. Index correction must be found and applied.

ORAL QUESTIONS

Q. 1. *What is a mirror?*

Ans. It is a highly polished surface which reflects most of the light that falls on it.

Q. 2. *What are different types of mirrors?*

Ans. (*i*) Plane and (*ii*) spherical (concave and convex).

Q. 3. *Why are mirrors silvered at the back surface?*

Ans. So that they may not get spoiled by rough handling.

Q. 4. *Does reflection take place from the silvered surface?*

Ans. Yes.

Q. 5. *Is silvering always of silver?*

Ans. No, in cheap mirrors silvering is done by deposition of mercuric oxide. In good mirrors silvering is done by deposition of silver nitrate.

Q. 6. *Where is the image formed in case of a plane mirror? What type?*

Ans. The image is as far behind the plane mirror as the object is in front of it and it is virtual, erect, of the same size and laterally inverted.

Q. 7. *How do you distinguish between a convex and a concave mirror?*

Ans. A spherical mirror is a curved reflecting surface which forms a part of a sphere and reflects light regularly. If the outer part is so polished that reflection takes place only at the concave surface, then the mirror is called a concave mirror and if the inner part is so polished that the reflection takes place only at the convex surface *i.e.*, outer part, then the mirror is called a convex mirror.

Q. 8. *Define pole, centre of curvature and radius of curvature of the mirror.*

Ans. Pole. It is the mid-point of a spherical reflecting surface.

Centre of curvature. It is the centre of a sphere of which the spherical mirror forms a part.

Radius of curvature. It is the radius of a sphere of which the mirror forms a part.

Q. 9. *Define aperture, principal axis, principal focus and focal length.*

Ans. Aperture. The aperture of the spherical mirror is the angle subtended by the face of the mirror at the centre of curvature (Fig. 21.5).

Principal axis. It is a line passing through the pole and the centre of curvature of a mirror.

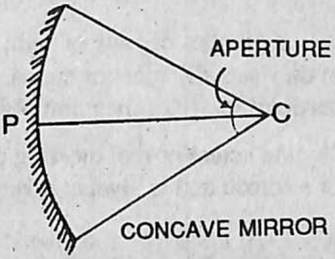


Fig. 21.5

Principal focus :

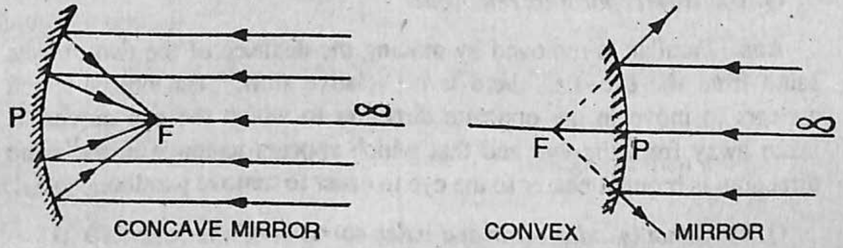


Fig. 21.6

If a narrow beam of parallel rays, parallel to the principal axis, after reflection converges to a point or appears to diverge from a point lying on the principal axis, the point is called principal focus of the spherical mirror (Fig. 21.6).

Focal length. The distance between the principal focus and the pole of the mirror is called focal length.

Q. 10. *What is the relation between the radius of curvature and focal length of the mirror?*

Ans. Focal length = $\frac{\text{Radius of curvature}}{2}$.

Q. 11. *What do you mean by curvature of the mirror?*

Ans. The reciprocal of the radius of curvature is called the curvature.

Q. 12. *What is an image? Distinguish between Real and Virtual Image?*

Ans. **Image.** Whenever a number of rays of light start from a point object and after reflection they actually meet or appear to meet at a point, then this point is known as point image of the point object.

Real image is formed by the actual or real meeting of the rays of light. Real image can be had on a screen and is always inverted with respect to the object.

Virtual image is not formed by the actual meeting of the rays of light and cannot be projected on a screen. Virtual image is always erect with respect to the object.

Q. 13. *What is parallax?*

Ans. The apparent shift between the two objects when they are at different distances from the eye is called parallax.

Q. 14. *How is parallax removed?*

Ans. Parallax is removed by making the distance of the two objects same from the eye, *i.e.*, there is no relative shift. The object which appears to move in the opposite direction to which the eye moves, is taken away from the eye and that which appears to move in the same direction, is brought nearer to the eye in order to remove parallax.

Q. 15. *What is index error and index correction?*

Ans. In an actual experiment on optical bench, we are required to measure the object and image distances from the pole of the mirror. The distance between the tip of the needle and pole of the mirror is the *actual* distance. But we practically measure distances between the *indices* with the help of the scale. These distances are called the *observed* distances.

The actual distances may not be equal to the observed distances. This correction is called *Index Correction.*

Index Error = (Observed distance) —(Actual distance) and

Index Correction = (Actual distance)—(Observed distance)

The index correction whether +ve or –ve is always added algebraically to the observed distance to get the corrected distance.

Q. 16. *What type of mirrors are used for :*

(a) Dressing table, (b) Shaving, (c) Driving a car, (d) Search light, (e) Street light.

Ans. (*a*) Plane mirrors of large size.

(*b*) Concave mirrors of large focal length.

(*c*) Convex mirror of short focal length.

(*d*) Concave Mirror of large aperture or Parabolic mirror.

(*e*) Convex Mirror.

Q. 17. *What are conjugate foci ?*

Ans. These are the two points lying on the principal axis of a concave mirror such that the object placed at one of these, produces an image at the other point.

Q. 18. *Do the conjugate foci exist in convex mirror?*

Ans. No, as it produces virtual image.

Q. 19. *Why is the mirror of small aperture taken?*

Ans. If the aperture is large, the image suffers from the defect of spherical aberration ?

Q. 20. *Why is the image formed by a convex mirror always diminished?*

Ans. Magnification $m = \frac{f}{u-f}$. Since 'f' is negative then $u-f>f$ and hence $m<1$.

Q. 21. *Can we find the rough focal length of a Convex Mirror?*

Ans. No, we cannot; because the image formed by a convex mirror is always virtual and thus cannot be had on a screen.

Q. 22. *What are the sign conventions while deriving the formula* $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ *for a spherical mirror?*

Ans. According to New Cartesian Convention :

(*i*) The incident ray is taken from left to right.

(*ii*) All distances are measured from the pole of the mirror as origin.

(*iii*) Distances, measured in a direction *opposite* to the incident ray direction, are taken *negative.*

(*iv*) Distances, measured in the *same* direction as the incident ray are taken *positive.*

(*v*) Distances measured *above* the principal axis are taken as *positive.*

Thus according to these sign conventions, the focal length of a *concave mirror* is *negative* and that of *convex mirror is positive.*

□ □

EXPERIMENT 22

To find out the focal length of a Convex Mirror using convex lens.

Apparatus :

Optical bench with four uprights, a convex mirror, a convex lens, two needles, a knitting needle and a metre rod.

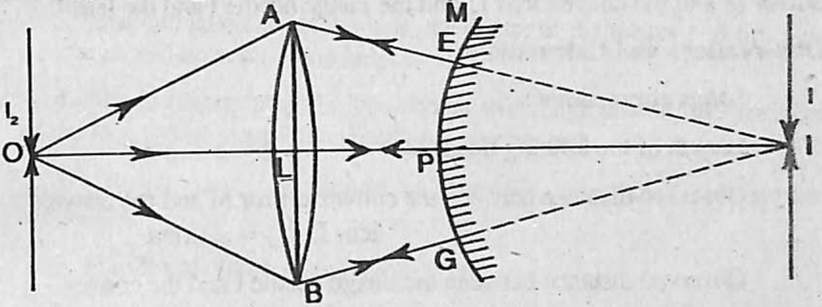


Fig. 22.1. Focal length of a convex mirror by convex lens

Theory :

Let O (Fig. 22.1) be a point object on the axis of a convex lens L and I its real image. On interposing a convex mirror M between L and I, and suitably adjusting its position so that I is its centre of curvature, the rays of light after refraction through the lens will then fall normally on it. They are reflected back along the original path and the real image is formed in coincidence with 'O' itself. Then PI is the radius of curvature 'r' of the convex mirror. The focal length is equal to *half* of this distance.

Procedure :

1. Find the rough focal length (f) of a convex lens by focussing the image of a distant object on a screen and measuring the distance between the lens and the screen.

2. Mount on the optical bench, a needle O, the convex lens L and convex mirror M as shown in Fig. 22.1, so that the tip of the needle, the centres of the convex lens L and the convex mirror M, are at the *same height* and O, the object needle is between f and $2f$ of the convex lens.

3. Adjust the position of the convex mirror M or needle O if necessary so that a real inverted image of 'O' is formed in coincidence with the needle itself. Remove parallax between the image of the needle and the needle itself.

4. Note the position of the mirror and remove it altogether. *Be careful not to alter the positions of the needle O and the lens L.* Then set

up another needle I on the other side of the lens and using the method of parallax, locate the position of the real image of 'O' as usual. Note the position of the needle I.

5. Repeat the experiment *three* times with different positions of the needle 'O' and lens 'L'.

6. Find index corrections between the uprights holding the convex mirror M and the convex lens L, and the image needle I and the lens L.

Observations and Calculations :

Index corrections :

Length of the knitting needle = x = ...*cm*

Observed distance between the convex mirror M and the convex lens L = y = ... *cm*

Observed distance between the image needle I and the convex lens L = z = ... *cn*

Index correction between the convex mirror M and the lens L

$$= (x - y) = \pm ..... cm$$

Index correction between the image needle I and the convex lens L $= (x - z) = \pm ... cm$

No. of obs.	Position of (in cm)		Observed (in cm)		Corrected		Radius of curvature of convex mirror $r = LI - LP$ (cm)
	Lens (L)	Convex mirror (P)	LP	LI	LP	LI	
1.							
2.							
3.							
4.							

Mean r = ... *cm*

Mean focal length, $f = \frac{r}{2}$ = ...*cm*

Result :

Focal length of the convex mirror = ... *cm*

Precautions :

1. The focal length of the convex lens should be greater than that of the convex mirror.

2. The distance between the convex mirror and the convex lens should be small.

3. The optical centre of the lens, the centre of the mirror and tip of the needle should be at the same height.

4. While determining the position of the image needle, the positions of the lens and object needle should not be changed.

5. Bench correction should be carefully determined and applied accurately.

6. Parallax should be removed tip to tip.

7. The planes of the convex mirror and the convex lens should be vertical and their principal axes in the *same* horizontal line.

ORAL QUESTIONS

(Same as in Experiment Nos. 21 and 23)

□ □

EXPERIMENT 23

To find the value of v for different values of u in case of a convex lens and hence find the focal length f by plotting of graphs between u and v and $\frac{1}{u}$ and $\frac{1}{v}$ or by calculation.

Apparatus :

(*i*) An optical bench with three uprights.

(*ii*) Two pointed needles.

(*iii*) Convex lens (short focal length).

(*iv*) One clamp.

(*v*) Half metre rod.

(*vi*) Knitting needle.

(*vii*) Screen of white paper.

Theory :

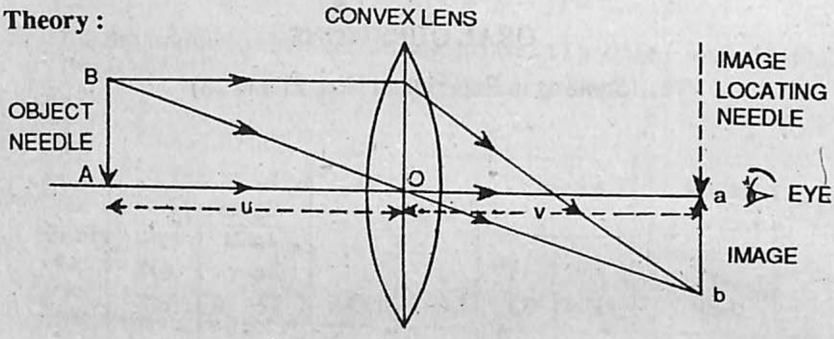


Fig. 23.1

When an object needle (AB) is placed in front of a convex lens at a distance greater than the focal length of the lens, its real, inverted image (ab) is formed on the other side. By placing a second needle there, the position of the image of the object needle can be located by removing the parallax between this image and the second needle itself. That is why the second needle is called the image locating needle. If *u* and *v* are the distances of the object and the image needle from the lens respectively, then focal length (*f*) is related as follows :

$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$ according to new sign conventions.

and magnification (*m*) is given by

$m=\frac{I}{O}=\frac{v}{-u}$ where I = size of the image
and O = size of the object

(1) Object at infinity

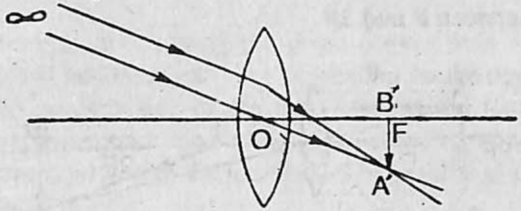


Fig. 23.2 (a) Object at infinity

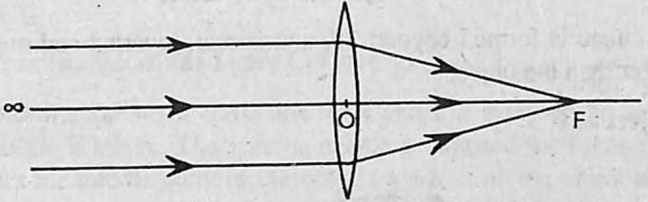


Fig. 23.2 (b)

The image of an object at infinity is formed at the principal focus, is real, inverted and very much reduced in size.

(2) Object beyond 2F

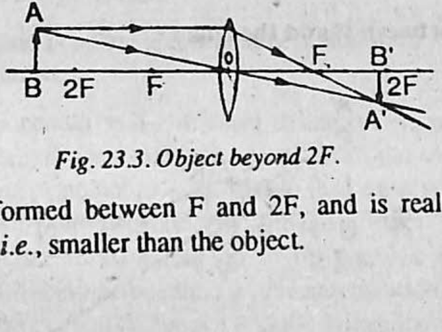


Fig. 23.3. Object beyond 2F.

The image is formed between F and 2F, and is real, inverted and diminished in size *i.e.*, smaller than the object.

(3) Object at 2F

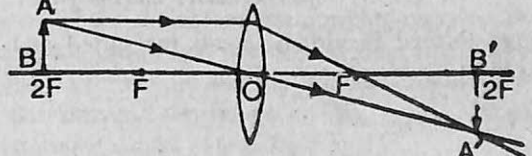


Fig. 23.4. Object at 2F.

The image is formed at 2F and it is real, inverted and equal in size.

(4) Object between F and 2F

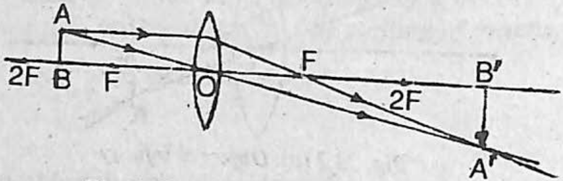


Fig. 23.5. Object between F and 2F

The image is formed beyond 2F, and is real, inverted and magnified *i.e.*, larger than the object.

(5) Object at F

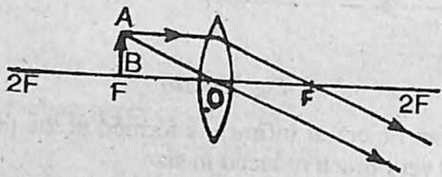


Fig. 23.6. Object at F

The image is formed at infinity and is real, inverted and extremely magnified.

(6) Object between F and the lens :

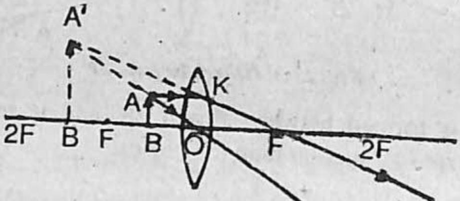


Fig. 23.7. Object between F and the lens

The image formed is virtual, erect; magnified and appears to lie behind the object.

Procedure :

1. Find the rough focal length of the given convex lens *i.e.*, focussing a sharp, clear and inverted image of a distance object on the white paper screen and determine the distance between the screen and the lens.

2. Mount the uprights carrying the given convex lens whose focal length is to be found and those carrying the needles on the optical bench. Keep one needle on each side of the lens. Adjust the heights of the needle tips so that these reach the middle of the convex lens as shown in Fig. 23.1. The principal axis of the lens should be parallel to the scale on the optical bench.

Mark one of the needles as the object needle and the other as the image needle.

3. Determination of the Index Correction

To determine the index correction for *u* and *v*, a sharp ended straight knitting needle is taken. The knitting needle is adjusted such that its one end touches the middle point of the convex lens. Now the object needle is brought near the other end of the knitting needle and then adjusted in such a way that the tip of the two coincide. Note the distance between the indices of the two uprights. This distance is the *observed distance.* Measure the length of the knitting needle which is equal to the *actual distance* on the principal axis. The difference of these two distances will give the *index correction* for the distance '*u*'.

Similarly find the index correction for '*v*' *i.e.*, for the distance between the convex lens and the image needle.

This * index correction is added algebraically to the observed distance to get the corrected distance.

4. Place the object needle at a sufficient distance *i.e.*, greater than twice the rough focal length from the lens. Look from the other side of the convex lens along its principal axis and locate the real inverted image formed with the help of second needle, *i.e.*, image needle. Adjust the position of the image needle such that tip to tip parallax is removed between the image and the image needle, *i.e.*, for any position of the eye, there is no relative shift between the image and the image locating needle (Fig. 23.1).

Note the positions of the indices of the uprights carrying the object needle, convex lens and the image needle and thus find the observed distance between the object needle and the lens *i.e.*, *u* and the observed distance between the lens and the image needle, *i.e.*, *v*. Apply index corrections to get corrected values of *u* and *v*.

---

* If the mounting of the uprights is not disturbed, the index corrections determined for *u* and *v* remain constant for all the readings. Also care should be taken not to rotate the uprights of the needles while shifting otherwise index error will change.

Select suitable scale (same scale) to represent the object distance *u* along the x-axis on the *negative side* (as *u* is —ve according to new sign conventions) and the image distance *v* along the y-axis on the *positive side*. Plot the points from the different observations and draw the curve joining these points. This should be a *rectangular hyperbola* as shown in the graph (Fig. 23.8). Draw a line making an angle of 45° with the x-axis. It cuts the curve at a point P. Draw PM and PN perpendiculars on the axis. Read the value of OM or ON. This gives '$2f$' where f is the focal length of the convex lens. Half of this will give the focal length of the convex lens.

Method No. 2 :

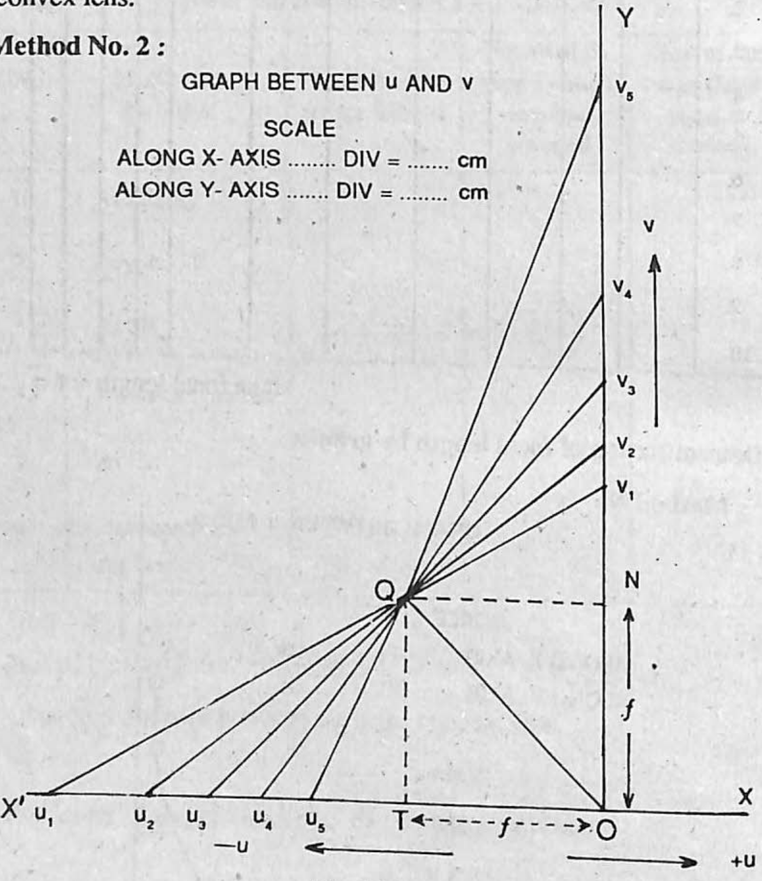
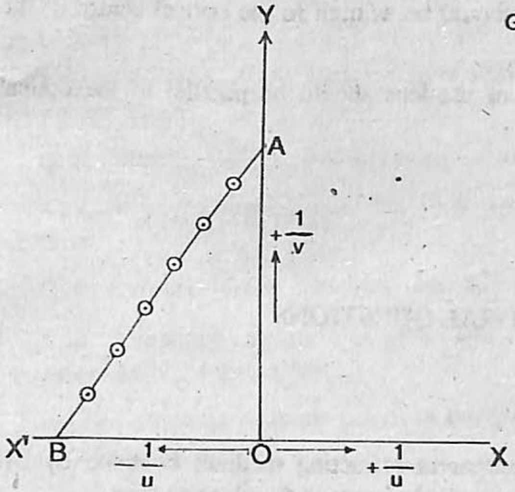


Fig. 23.9

Select proper scale (same scale) to represent *u* along the x-axis along —ve direction (according to new sign conventions) and v along the y-axis along +ve direction. Draw lines joining $u_1, v_1; u_2, v_2; u_3, v_3;$ etc. These intersect at the point Q; draw perpendiculars QT and QN. Read the values of ON or OT. This will give directly 'f', the focal length of the convex lens (Fig. 23.9).

Method No. 3 :



GRAPH BETWEEN $\frac{1}{u}$ AND $\frac{1}{v}$

SCALE
ALONG X- AXIS
.... DIV = ... cm
ALONG Y- AXIS
...... DIV = ... cm

Fig. 23.10

Select proper scale (same scale) to represent $\frac{1}{u}$ along x-axis along —ve direction (according to new sign conventions) and $\frac{1}{v}$ along the y-axis along +ve direction. Plot the points and join these by the line AB (Fig. 23.10). This will cut the x-axis at 45°. Measure OA or OB.

Then focal length of the convex lens $f = \frac{1}{OA}$ or $\frac{1}{OB}$.

Result :

The focal length of the convex lens comes out

(1) By calculation focal length f = ...cm

(2) From Graph No.1, focal length f = ...cm

(3) From Graph No. 2, focal length f = ...cm

(4) From Graph No. 3, focal length f = ...cm

Precautions :

1. The parallax should be removed from tip to tip.

2. Index corrections for *u* and v should be carefully noted and applied separately.

3. The uprights snould be vertical, stable and not shaky.

4. For clear image, a little chalk should be applied on the side of the object needle facing the lens.

5. Eye should be placed at a distance of about 100 cm from the image needle while removing parallax.

6. Tips of the needles should be as high as the optical centre of the lens.

7. The principal axis of the lens should be parallel to the optical bench scale.

Sources of Error :

Thickness of the lens.

ORAL QUESTIONS

Q. 1. *What is a lens?*

Ans. A lens is a transparent refracting medium bounded by two spherical surfaces or by a spherical surface and a plane surface.

Q. 2. *What is a convex lens?*

Ans. A convex lens has its two spherical surfaces bulging outwards at the centre. The thickness of the lens is more in the middle than at periphery. It is a converging lens.

Q. 3. *What is a concave lens?*

Ans. A concave lens has its two spherical surfaces bulging inwards at the centre. The thickness of the lens is less in the middle than at the periphery. It is a diverging lens.

Q. 4. *What types of convex lens are there?*

Ans. (*i*) Double convex (*ii*) Plano-convex (*iii*) Concavo-convex.

Q. 5. *What types of concave lens are there?*

Ans. (*i*) Double concave (*ii*) Plano-concave (*iii*) Convexo-concave.

Q. 6. *Define Principal Axis and focal length?*

Ans. Principal axis is the line joining the centres of curvatures of the two surfaces of the lens.

Focal length is the distance of a point (focus) from the optical centre of the lens, where a beam of parallel rays after passing through the lens actually converges or appears to diverge from a point called the focus.

Q. 7. *Define optical centre and aperture of a lens.*

Ans. *Optical centre* is the point which divides the line joining the centres of curvature of the lens inversely in the ratio of the radii of curvature of the two surfaces. Also a ray of light passing through this point is undeviated.

Aperture is the angle subtended by the diameter of the surface of the lens at the focus.

Q. 8. *What do you mean by the power of the lens? What is its unit?*

Ans. It is the reciprocal of the focal length in metres. Its unit is *dioptre.*

Q. 9. *Define centre of curvature and radius of curvature.*

Ans. *Centre of curvature* is the centre of the sphere of which the spherical surface forms a part.

Radius of curvature is the radius of the sphere of which the spherical surface forms a part.

Q. 10. *What is the radius of curvature of a plane surface?*

Ans. The radius of curvature of a plane surface is infinity.

Q. 11. *What is the difference between focus and the Principal focus?*

Ans. *Focus* is any point in the focal plane where a parallel beam of light after refraction converges or appears to diverge from.

Principal focus is the point where a beam parallel to the principal axis converges or appears to diverge from a point on the principal axis after passing through the lens.

Q. 12. *What is the nature of the image formed in a convex lens?*

Ans. The image formed is real and inverted for all positions except when the object lies between optical centre and principal focus where the image formed is virtual, erect and magnified.

Q. 13. *Will the convergent lens behave always as convergent and divergent lens as divergent?*

Ans. No; a convergent lens becomes divergent one and a divergent lens becomes convergent when placed in an optically denser medium than itself *e.g.*, CS_2 whose refractive index is 1·63.

Q. 14. *What is the difference between a real and a virtual image?*

Ans. The image is said to be *virtual* if rays of light after reflection or refraction do not actually meet but appear to diverge from a point. Virtual image is always erect.

The image is *real* if the rays of light actually meet at a point. It is always inverted.

Q. 15. *Can we find rough focal length of a concave lens?*

Ans. No, because the image formed by a concave lens is virtual and cannot be taken on the screen.

Q. 16. *Is the focal length of a thick convex lens greater than that of a thin one?*

Ans. The focal length of a *thin* convex lens is greater than that of a thick one.

Q. 17. *On what factor does the focal length of a lens depend?*

Ans. The focal length of a lens depends upon the radii of curvature of its surfaces and the refractive index of the material of the lens. Also it depends upon the colour of the incident light.

Q.18. *What is the relation between the focal length and radii of curvature? What are sign conventions?*

Ans. $$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] = \frac{1}{v} - \frac{1}{u}$$

Where f = focal length

μ = Refractive index

u = Object distance

v = Image distance

R_1. R_2 = radii of curvature

According to New Cartesian Sign Convention :

(*i*) The incident rays of light are taken from *left* to *right*.

(*ii*) All distances are measured on the principal axis of the lens *from the optical centre of the lens as origin.*

(*iii*) Distances measured in a direction *opposite* to the incident ray direction, are taken *negative* while distances, measured in the *same* direction as the incident ray are taken as *positive*.

(*iv*) Distances measured *above* the principal axis are taken *positive* while distances measured *below* the principal axis are taken *negative*.

Thus according to these sign conventions, the focal length of a *convex lens is positive* and that of *concave lens* is *negative*.

Q. 19. *What are the practical uses to which a lens can be put?*

Ans. (*i*) Magnifying glass

(*ii*) Optical lantern

(*iii*) Photographic camera

(*iv*) Telescopes and microscopes.

(*v*) Spectacles

(*vi*) Stereoscope etc., etc.

Q. 20. *What happens if a ray of light falls normally at the surface of separation of two media?*

Ans. It goes undeviated.

Q. 21. *What is parallax? When is the parallax removed?.*

Ans. *Parallax* is the relative displacement between the two objects when they are at different distances from the eye.

The parallax is removed when the two objects are at the same distance from the eye.

Q. 22. *At what distance should the eye be placed from the needle while removing the parallax?*

Ans. It should be at distance more than the least distance of distinct vision which varies from 25 cm to 30 cm for a normal eye.

Q. 23. *Why are the images formed by a lens usually curved and coloured?*

Ans. Due to spherical aberration and chromatic abberation.

Q. 24. *What is spherical aberration ?*

Ans. The defect of a lens due to which it is unable to focus the marginal and central rays to a single point is called the spherical aberration. The image formed due to this defect is blurred (Fig. 23.11).

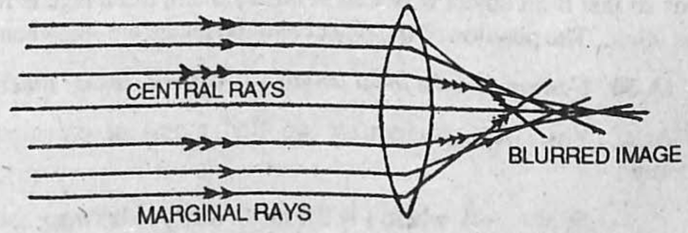


Fig. 23.11 Spherical aberration

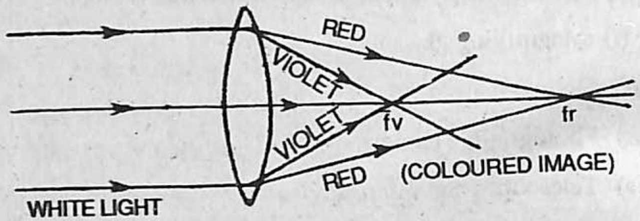


Fig. 23.12 . Chromatic aberration

Q. 25. *What is chromatic abberation?*

Ans. The defect of a lens due to which it is unable to focus all the colours to a single point is called chromatic aberration. The image formed due to this defect is coloured (Fig. 23.12).

Q. 26. *What is index correction?*

Ans. It is the correction applied to observed distance in order to get correct distance.

Index correction = Actual length of the knitting needle—observed length of the knitting needle.

Q. 27. *How will you distinguish between a convex and a concave lens?*

Ans. Look at distance object through the lens. On moving the lens sideways if the object seems to move in the opposite direction, the lens is concave.

Q. 28. *For what position of the object will you get a natural image in case of a convex lens?*

Ans. When the object lies at 2F, *i.e.*, twice the focal length of the convex lens.

Q. 29. *What are conjugate foci?*

Ans. Conjugate foci are those points on the principal axis of a convex lens so that if an object is placed at one of them, the image is formed on the other. The position of the object and the image are interchangeable.

Q. 30. *Can we find the focal length of a convex lens by spherometer?*

Ans. Yes. By spherometer we find radius of curvature by the formula.

$R = \frac{l^2}{6h} + \frac{h}{2}$ where l is the mean distance between the legs and

'h' is the difference between the readings on the plane surface and curved surface. Further focal length $f = \frac{R}{2}$.

Q. 31. *Can we use a concave lens as a magnifier?*

Ans. No, because the image formed in a concave lens is always smaller than the size of the object.

Q. 32. *Why is the image in a concave lens always diminished?*

Ans. Because in this case magnification $m = \frac{-f}{u+f}$ which is always less than one numerically. Therefore image is diminished.

Q. 33. *If a lens of* $\mu = \frac{3}{2}$ *is immersed in water of* $\mu = \frac{3}{4}$, *how will its focal length change?*

Ans. It will become four times.

Q. 34. *Can you use a screen in place of the image needle in case of a convex lens?*

Ans. Yes, because real and inverted image can be obtained on a screen.

Q. 35. *Where should the object needle be placed to get (a) Real, diminished image; (b) Real, enlarged image; (c) Virtual image.*

Ans. (*a*) Beyond 2F (*b*) between F and 2F (*c*) between optical centre and principal focus.

Q. 36. *How will you use the convex lens as a magnifier?*

Ans. By placing the object within the focus of the convex lens.

□□

EXPERIMENT 24

To find out the focal length of a concave lens using convex lens.

Apparatus :

Optical bench with three uprights, concave lens; convex lens of greater power than the given concave lens; two needles; knitting needle; half-metre rod, a clamp stand, a cork and a screen.

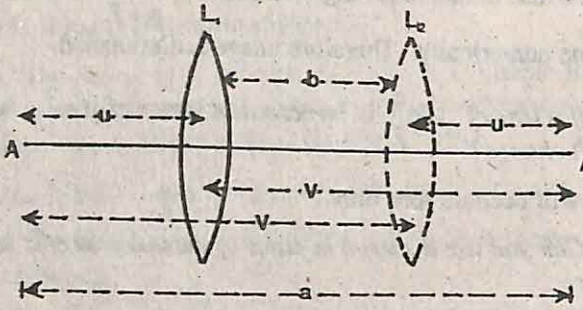


Fig. 24.1

Theory :

If the object needle A and the image needle A′ be separated by a distance greater than four times the rough focal length of a convex lens then there are two positions L_1 and L_2 of the convex lens for which real, inverted, images of the object needle may be obtained so that there is no parallax with the image needle A′. For the position L_1 of the convex lens, the image at A′ of the object needle A is real, inverted and magnified, while for the position L_2 of the convex lens it is real, inverted and diminished.

Let the distances between A and A′ the object needle and the image needle respectively, be denoted by '*a*' and that between L_1 and L_2, the two positions of the lens by '*b*'. It is found that due to symmetrical positions of the lens.

$$u = AL_1 = A'L_2$$

and $$v = A'L_1 = AL_2$$

∴ $$v + u = a$$

and $$v - u = b$$

and hence $u = \frac{a-b}{2}$ and $v = \frac{a+b}{2}$

and the focal length 'f' is given by

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{2}{(a-b)} + \frac{2}{(a+b)}$$

or $$\boxed{f = \frac{a^2 - b^2}{4a}} \qquad \text{..........} (i)$$

If a concave lens of focal length f_2 is placed in contact with a convex lens of focal length f_1 so that the combination is convex with focal length F, then

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

or $$\boxed{f_2 = \frac{Ff_1}{f_1 - F}} \qquad \text{..........} (ii)$$

Knowing F and f_1, the focal length of a concave lens 'f_2' can be calculated.

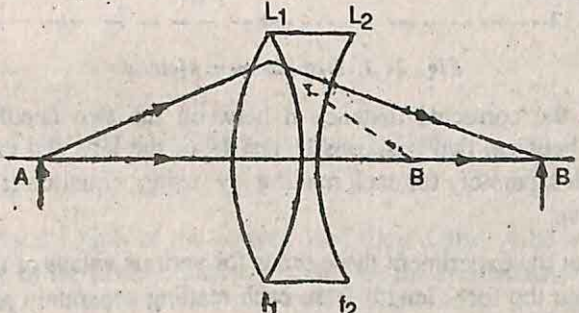


Fig. 24.2

Procedure :

1. Select a suitable convex lens, so that by combining it with the given concave lens, the combination behaves as a convex lens and find the rough focal length of this convex lens and that of the combination separately. Determine the index correction between the two needles only.

2. Find separately the mean focal length F of the combination and f_1 of the convex lens, by displacement method as follows:

3. Place both the lenses in contact in the holder and mount it on a vertical upright. Make the plane of the combined lens vertical so that its principal axis is horizontal and parallel to the base of the optical bench. Place the uprights carrying needles at a distance greater than four times the rough focal length of the combined lens. Place upright carrying the lens in between the needles and move it towards and away from the object needle AB till there is no parallax between the needle AB and its image A′B′. Note down the position L_1 of the lens. Also record the positions of the needle. (Fig. 24.1).

4. Now shift the lens to the position L_2 *without disturbing the needles* and adjust the position of the lens till there is no parallax between the needle XY and its real, inverted and diminished image X′Y′. Note down the position L_2 of the lens.

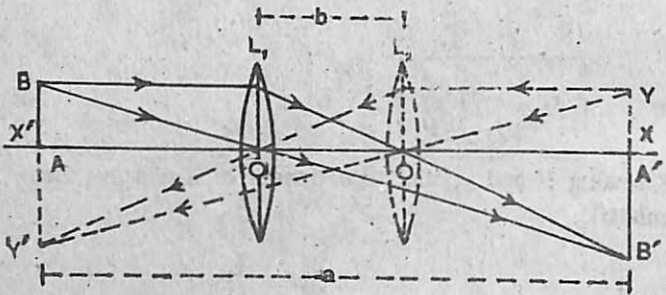


Fig. 24.3. Displacement Method

5. Find the corrected distance *a* between the two needles and the distance *b* between two positions L_1 and L_2 of the lens and calculate the focal length separately for each reading by using equation (*i*) given in theory above.

6. Repeat the experiment three times for various values of the distance *a*. Calculate the focal length from each reading separately and take the mean of the focal length *F*.

7. Similarly calculate the focal length f_1 of the convex lens by displacement method and then find f_2 by using equation (*ii*) given in theory above.

Observations :

Rough focal length of the convex lens =......*cm*

Rough focal length of the combination =......*cm*

Actual length of the knitting needle (y) =......*cm*

Observed distance between the two needles (x) =......*cm*

Index correction for $a = \pm (y - x)$ =......*cm*

Table for the focal length of lenses

Lens	S. No.	Position of		Obs. (a) in cm	Cor. (a) in cm	Position of		(b) in cm	$f = \frac{a^2 - b^2}{4a}$ in cm	Mean in cm
		Object needle in cm	Image needle in cm			L_1 in cm	L_2 in cm			
Convex	1.									
	2.									$f_1 = ...$
	3.									
Combination	4.									
	5.									F = ...
	6.									

Calculations :

$$f_1 = \frac{a^2 - b^2}{4a} = ... \text{cm.,} \quad F = \frac{a^2 - b^2}{4a} = ... \text{cm}$$

and $$f_2 = \frac{Ff_1}{f_1 - F} = ... \text{cm}$$

Result :

Observed focal length of the given concave lens = ...cm

Precautions :

1. The focal length of the convex lens should always be less than the focal length of the given concave lens so that the combination *behaves as a convex lens.*

2. The distance between the two needles should always be greater than four times the rough focal length of the convex lens otherwise no displacement is possible. For convenience this distance should not exceed six times the focal length of the lens.

[Note : $f = \frac{a^2 - b^2}{4a}$

Let $a = 4f$

then $b = 0$ *i.e.*, the displacement in the position of the lens is possible.]

3. While taking the second position of the lens, the needle should not be disturbed.

4. Tip to tip parallax should be removed.

5. The uprights should be vertical, stable and not shaky.

6. For clear image, a little chalk should be applied on the tip of the object needle.

7. Eye should be placed at a distance of about 100 cm from the needle while removing parallax.

ORAL QUESTIONS

(Same as in Experiment No. 23)

□□

EXPERIMENT 25

To find the focal length of a concave lens by an auxiliary convex lens (not in contact).

Apparatus:

Optical bench with uprights; concave lens; convex lens; two pointed needles; bench correction rod (knitting needle).

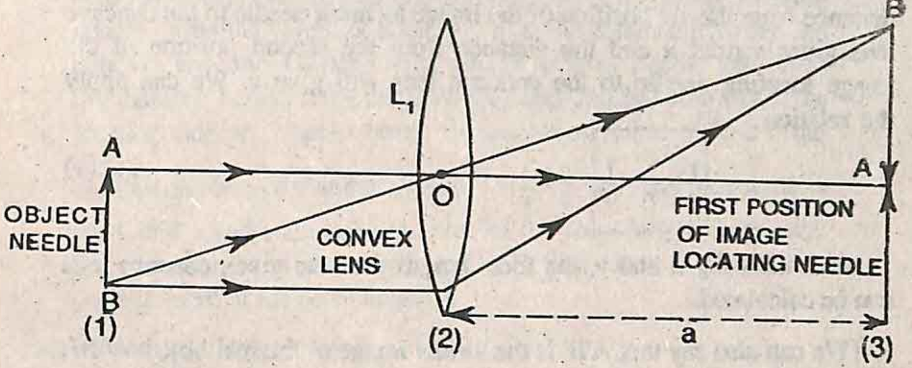


Fig . 25.1

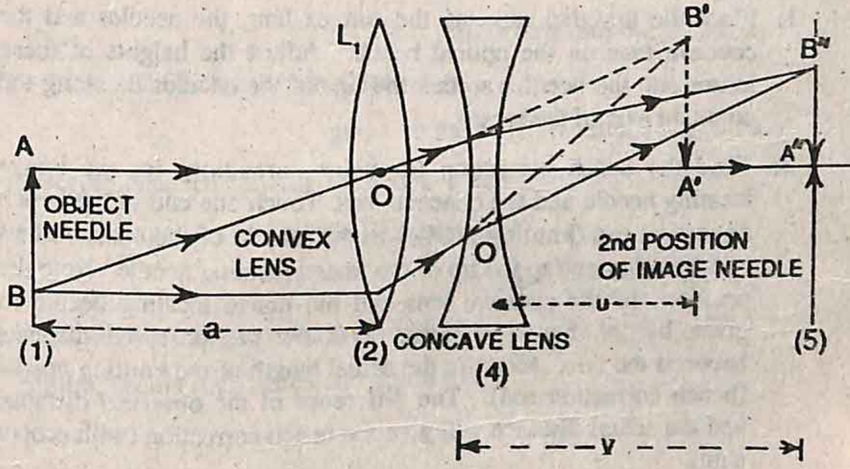


Fig . 25.2

Theory :

If an object AB be taken and placed at some distance from a convex lens L_1, a real image A'B' will be obtained which can be located with the help of a second needle as shown in Fig. 25.1.

If the concave lens whose focal length is to be found is placed in between the image locating needle and the convex lens, it will divulge the rays and the real image A"B" (Fig. 25.2), will now be formed at some farther distance. To locate its exact position the image locating needle will have to be shifted.

Now we can suppose that A'B' serves as a *virtual* object for this concave lens and A"B" is the image formed in this case. Therefore, the distance from the 1st position of the image locating needle to the concave lens gives virtual *u* and the distance from the second position of the image locating needle to the concave lens will give *v*. We can apply the relation

$$\boxed{\frac{1}{f}=\frac{1}{v}-\frac{1}{u}} \qquad \text{......(1)}$$

Thus knowing *u* and *v*, the focal length *f* of the given concave lens can be calculated.

[We can also say that A'B' is the virtual image of the real object A"B". Therefore O'A" = *u* and O'A' = v and *v* will be taken as *negative*.]

Procedure :

1. Place the uprights carrying the convex lens, the needles and the concave lens on the optical bench. Adjust the heights of these lenses and the needles so that the tips of the needles lie along the common axis of the lenses.
2. Find the bench correction (or index correction) for the image locating needle and the concave lens. Touch one end of the bench correction rod (knitting needle) to the middle of the concave lens and the other end to the tip of the image locating needle. Note the positions of the concave lens and the image locating needle as given by the bench readings, to know the observed distance between the two. Measure the actual length of the knitting needle (bench correction rod). The difference of the observed distance and the actual distance will give the bench correction (with proper sign).
3. Remove the concave lens from the bench keeping only the convex lens on it. Keep the first needle to serve as the object needle at such a distance (more than the rough focal length) from the convex lens so that a real image is obtained by the lens. Locate the position of the image so formed with the help of the image

locating needle. Move the image locating needle till there is no parallax between the image and the image locating needle. Note the positions of the object needle, convex lens and the image locating needle.

4. Mount the concave lens in between the image locating needle and the convex lens. It should be nearer to the image needle. Shift the image locating needle to a position where there is no parallax again between the image and the image locating needle. Note the position of the concave lens and 2nd position of the image locating needle. Find the values of u and v. 'u' is the distance between the concave lens and 1st position of image locating needle and 'v' is the distance between the concave lens and 2nd position of image locating needle. Apply bench or index correction to know the corrected values of u and v. Apply $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$ and use proper signs for u and v and calculate the value of the focal length from each set of observation separately and take the mean to know the correct value of the focal length.

Observations and Calculations :

For Bench Correction or Index Correction :

(1) Position of the concave lens as given by the

Bench reading =............*cm*

(2) Position of the image locating needle as

given by the bench reading =..........*cm*

(3) Observed distance between the concave lens

and the image locating needle [Difference of

(1) and (2)] $=x=$.........*cm*

(4) Actual distance as given by the length of

knitting needle (*i.e.*, bench correction rod)

$=y=$.....*cm*

(5) Difference between the actual distance and

the observed distance $=(y-x)=$......*cm*

(This is also called *index error*.)

(6) Bench correction or Index correction

$= \pm (y - x) = \pm$ .....*cm*

Rough focal length of convex lens =......*cm*

Result :

The focal length of the given
concave lens by an auxiliary
convex lens (not in contact) comes out =......*cm*

Precautions :

1. The tip of the object needle and the image locating needle should reach the optical centres of the lenses.
2. The principal axes of the lenses should coincide and should be parallel to the optical bench.
3. The lenses must be clean.
4. The parallax should be removed from tip to tip.
5. The uprights should be vertical, stable and not shaky.
6. Index corrections (bench corrections) for *u* and *v* should be carefully noted and applied separately.
7. The focal length of the convex lens should neither be too large nor too small in comparison with that of the given concave lens so as to form a real inverted image A"B" (Fig. 25.2).
8. *The distance O'A' should be less than the focal length of the concave lens otherwise no real image is possible after refraction through the concave lens. The concave lens should, therefore, be placed between the convex lens and image A'B', closer to A' than the convex lens.* **The best value is obtained when O'A' and O"A" differ sufficiently.**

EXPERIMENT 26

(a) To determine the radii of curvature of the faces of a convex lens (by Boy's method).

(b) To determine the refractive index of the convex lens (by Boy's method).

Apparatus :

Convex lens of focal length 15-30 cm; and preferably not equiconvex; optical pin fitted in a cork; mercury; trough; clamp stand; half metre-rod; vernier callipers; plane mirror; knitting needle and rubber band.

Theory :

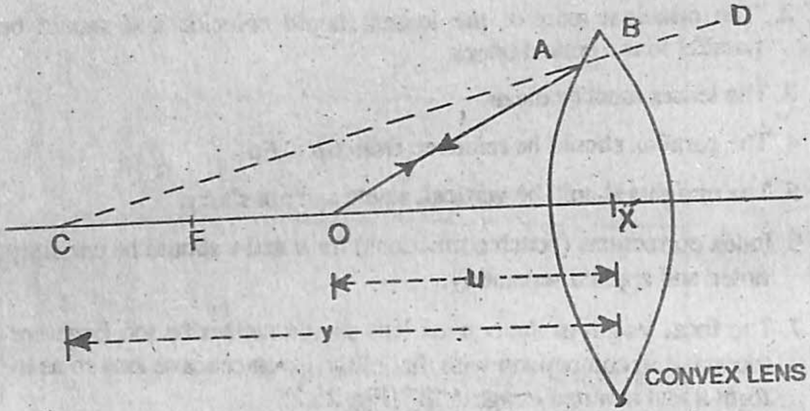


Fig . 26.1

Reflection always takes place at the interface of any two transparent substances. Therefore the faces of the lenses can be used as mirrors to determine their radii of curvature. In Fig. 26.1, O represents the object and OAB the path of a ray of light which strikes the back surface of the lens *normally* and so returns along the path of incidence, forming an image also at O. Some of the light will emerge from the lens along BD, without further deviation, and an observer on that side of the lens would see a virtual image of O at C, where DA produced cuts the axis of the lens. Since AB was normal to the face of the lens it is evident that C is the centre of curvature of that face. If the distance XC is y we have the relationship

$$\frac{1}{y}-\frac{1}{u}=\frac{1}{f} \quad \text{using new sign convention.}$$

where u is the object distance (OX), and f is the focal length of the lens.

From this relation, y can be calculated and hence the radius of curvature of the face

$$= r_1 = y + \frac{t}{2} \text{ where t is the thickness of the lens.}$$

[It is important to realise that when the object coincides with its image at O (formed by one internal reflection), O is NOT the centre of curvature of the surface at which reflection is occurring. The radius can only be found by the calculation given above.]

Thus knowing the radii of curvature of the two faces of the convex lens, the refractive index (μ) of the glass of which the lens is made can be found by substituting the values in the equation

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

where f = focal length of the lens

r_1, r_2 = radii of curvature of the two faces of the lens.

Procedure :

1. Find the thickness (t) of the convex lens near its centre by using Vernier Callipers.

2. **Rough Focal Length :**

   Obtain a sharp image of a *distant* object on a sheet of paper or the wall of the laboratory with the convex lens. If the sun is shining it forms the best object, but a laboratory window will do. The distance between the convex lens and the image, measured roughly with a metre rule would give the approximate focal length of the lens.

3. **Focal Length of Convex Lens :**

   Put a plane mirror on the bench or floor and place the convex lens on it. Above the combination put an optical pin fitted in a cork held in a clamp at a distance nearly equal to its rough focal length. Stand so that, when looking vertically down, the pin and its image can be seen. Adjust the position of the pin, so that it is in the same horizontal plane as its image *i.e., so that the tip of the pin and the corresponding tip of the image coincide* and exhibit no parallax. Make the *necessary measurements to find the distance of the pin from the optical centre of the lens. This distance is equal to the focal length (f) of the lens. Repeat several times to obtain an average value of f.

---

*Either use a plumb line or a knitting needle attached to a half metre rod. Measure the length of the knitting needle and attach it to the edge of the half metre rod, which is graduated in cm, by means of a rubber band such that 8 to 10 cm length of the needle is projected outside the rod. Measure the distance with the half metre rod and add the length of the projected portion of the needle.

4. Clean the faces of the convex lens and float it in a trough of clean mercury. Place a pin, held in a clamp, above it and adjust its position, by the no parallax method, so that, on looking downwards, the image formed by reflection, and the object are coincident. Make the necessary measurements to find the distance of the pin from the optical centre of the lens. This gives us the value of μ.

5. Repeat for the other face of the lens.

Observations and Calculations :

For thickness of the convex lens :

Vernier constant (V.C.) of Vernier Callipers = ...*cm*

Zero error of Vernier Callipers :

(1)..........*cm* (2) ....*cm* (3) ....*cm*

Mean Zero Error = ...*cm*

Mean Zero Correction = ± ....*cm*

S. No.	Main Scale reading (a)	No. of Vernier division coincident (n)	Vernier Scale reading $= n \times v.c.$	Observed thickness of the lens $= (a) + n \times v.c.$	Corrected thickness of the lens = observed thickness + Mean Zero correction	Mean corrected thickness of the lens (t)
1	...*cm*		...*cm*	...*cm*	...cm	...cm
2						
3						
4						

For focal length of the convex lens :

Rough focal length of the convex lens =......... *cm*

S. No.	Distance between the tip of the optical pin and the optical centre of the lens when tip to tip parallax is removed	Average value of the distance	Focal length of the convex lens = f
1	.....*cm*	..... *cm*	.....*cm*
2	.....*cm*		
3	.....*cm*		
4	.....*cm*		

Radii of curvature of the two faces of the lens:

	First Face of Convex Lens			
S. No.	Distance between the tip of the optical needle and the optical centre of the lens when tip to tip parallax is removed and the lens is floating in mercury	Average value of this distance $= u_1$	Distance $y_1 = \frac{fu_1}{u_1 + f}$	Radius of curvature $r_1 = y_1 + \frac{t}{2}$
1	.....*cm*	.....*cm*	.....*cm*	.....*cm*
2	.....*cm*			
3	.....*cm*			
4	.....*cm*			

	Second Face of Convex Lens			
S. No.	Distance between the tip of the optical needle and the optical centre of the lens floating in mercury when tip to tip parallax is removed	Average value of this distance $= u_2$	Distance $y_2 = \frac{fu_2}{u_2 + f}$	Radius of curvature $r_2 = y_2 + \frac{t}{2}$
1	.....*cm*	.....cm	.....cm	.....cm
2	.....*cm*			
3	.....*cm*			
4	.....*cm*			

Refractive Index of the Lens

Substitute the values of f, r_1 and r_2 in the formula

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$$

$$\therefore \quad \mu = \ldots\ldots\ldots$$

Result :

(*a*) The radius of curvature of one face

of the convex lens = r_1 = ...*cm*

The radius of curvature of the other face

of the convex lens = r_2 = ...*cm*

(*b*) The refractive index of the convex lens

by Boy's method = μ =.........

Precautions :

1. The convex lens should be of large focal length and aperture.
2. Remove parallax tip to tip carefully.
3. While using the formula $\frac{1}{f}=(\mu-1)\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$ appropriate sign convention should be used *i.e.*, give signs to r_1, r_2 and f accurately according to *new sign convention.

[***New sign convention :**

(*i*) The light rays will be taken to be travelling from the *left* to the *right*.

(*ii*) Distances are measured from the optical centre of the lens.

(*iii*) Distance on the *right hand side* of the optical centre will be taken as *positive* while those on the left hand side as *negative* or the distances measured in the same direction as that of incident light are taken as *positive* and the distances measured against the direction of incident light are taken as *negative*.

(*iv*) Focal length of convex lens will be taken as *positive* while those for a concave lens as *negative*.]

Note :

(*i*) Strictly speaking the addition of half the thickness of the lens in the above calculation only applies to equiconvex lenses. Most lenses conform so closely to this specification that the assumption is justified.

(*ii*) **The method can be applied to concave lenses more easily.** The reflection takes place, in this case, at the front face and a direct measurement of the required radius of curvature can be made when a position of coincidence of image and object has been found. *Obviously the mercury is not required* but a **dark cloth** is essential to form a background which absorbs light.

(*iii*) It is worth remembering that an equiconvex lens made of glass of refractive index 1·5 will have faces of radius of curvature equal to the focal length (the student should prove this for himself). Many lenses, however, are made of glass of much higher refractive index (*e.g.* 1·65).

Exercise :

To determine the refractive index of a liquid, using a convex lens and a plane mirror (an application of Boy's method).

Apparatus :

Convex lens of focal length about 10 cm; plane mirror, optical pin fitted in a cork; liquid *e.g.*, glycerine of which the refractive index is required; mercury; clamp stand; metre-rule; knitting needle; rubber band; vernier callipers.

Theory :

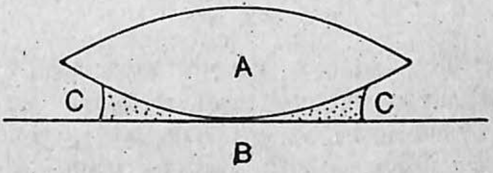


Fig. 26.2

If a liquid of refractive index μ, is flooded between a convex lens A and a plane mirror B as shown in Fig. 26.2, a concave lens made of the liquid is formed between A and B. A determination of the focal lengths of A and of the combination of A with C (the liquid concave lens) enables the focal length of the latter (f_c) to be found from the equation :

$$\frac{1}{F}=\frac{1}{F_A}+\frac{1}{f_c}$$

where F = focal length of the combination

and F_A = tocal length of the convex lens A.

Now the radii of curvature of the faces of the liquid lens are as (*i*) that of the under surface of the lens A and (*ii*) the plane surface of B. It is thus a plano-concave lens, and the general equation

$$\frac{1}{f_c} = (\mu - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

reduces to

$$\frac{1}{f_c} = (\mu - 1)\frac{1}{r}$$

where r is the radius of curvature of the under surface of A. ($\frac{1}{r_2}$ is zero since r_2 is infinite).

Thus the determination of the focal lengths of A and of the combination, together with a determination of r, enable the refractive index to be calculated.

Procedure :

Using the pin method of Experiment 26, find the focal length of the convex lens. Next introduce the liquid between the lens and the plane mirror, making sure that it thoroughly wets the lower surface of A and the upper one of B as this improves the distinction of the image. Find the focal length of the combination. Find the radius of curvature of the *under surface* of Lens A using Boy's method.

Observations and Calculations :

Record all your observations and deduce the result by the method given earlier in Expt. 26.

□ □

EXPERIMENT 27

To study the variation of angle of Deviation (D) with angle of incidence (i) for a glass prism and to determine the angle of minimum deviation. Find the relationship between ∠i and ∠D when ∠D is minimum. Can this be used for determining refractive index? If yes, then how?

Apparatus :

- (*i*) Glass Prism
- (*ii*) Drawing Board
- (*iii*) Pins
- (*iv*) Metre Scale
- (*v*) Protractor
- (*vi*) Sheets of white paper

Theory :

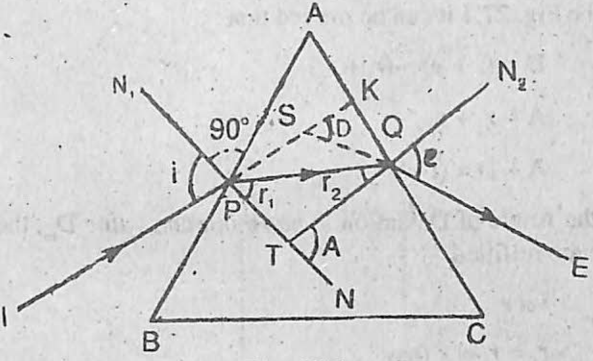


Fig. 27.1

When a ray of light passes from one medium into the other, it either bends towards the normal or away from the normal in the second medium depending upon whether the second medium is denser with respect to the first medium or is rarer. This phenomenon is known as the refraction of light.

For a particular pair of two media and for a particular wavelength of light (colour) the ratio of the sine of angle of incidence and the sine of the angle of refraction is a constant quantity called the refractive index of the second medium with respect to the first medium. It is represented by ${}^1\mu_2$. Therefore,

$$ {}_1\mu_2 = \frac{\sin i}{\sin r} \qquad .....(i) $$

The value of the angle of incidence i can be obtained in terms of the refracting angle A of the prism and the angle of minimum deviation D_m and the angle of refraction 'r' can also be obtained in terms of the refracting angle A of the prism.

Let ABC represent a section of the glass Prism and let IP be a ray incident at an angle i on the first face AB of the prism at a point P. N_1PN is the normal to this face. The material of the prism is denser with respect to air, as such the ray will refract in the direction PQ making an angle r_1 with the normal reaching the second face AC of the prism at the point Q making an angle r_2 with the normal N_2QT. The ray emerges in the direction QE bending away from the normal and making an angle 'e' with the normal.

If the emergent ray EQ be produced backward to meet IPK at S, then the angle KSQ is called the Angle of Deviation and is represented by 'D'. Angle BAC is called the Refracting Angle of the Prism and represented by A.

From the Fig. 27.1 it can be proved that

$$D = (i + e) - (r_1 + r_2) \quad \text{....}(ii)$$

and $$A = r_1 + r_2. \quad \text{...}(iii)$$

$$\therefore \quad A + D = (i + e) \quad \text{...}(iv)$$

When the Angle of Deviation D *has minimum value* D_m, the following conditions are fulfilled

$$i = e$$

$$r_1 = r_2 = r \text{ (say)}$$

Applying these conditions in equations (*iii*) and (*iv*).

$$A = 2r$$

or $$\boxed{r = \frac{A}{2}} \quad \text{...}(v)$$

and $$A + D_m = 2i$$

or $$\boxed{i = \frac{A + D_m}{2}} \quad \text{...}(vi)$$

Since the refractive index is given by the relation (*i*) according to which

$$_1\mu_2 = \frac{\sin i}{\sin r}$$

We obtain on substituting the values of *i* and *r*,

$$^1\mu_2 = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} \quad \text{...}(vii)$$

Thus we find that we can use the relation (*vii*) for determining the refractive index. The experiment thus consists in finding the value of the refracting angle A of the prism and the value of the angle of minimum deviation D_m.

For finding the value of D_m a curve is plotted between angles of incidence (*i*) and their respective angles of deviation (D).

Procedure :

(1) Refracting Angle 'A' of the Prism

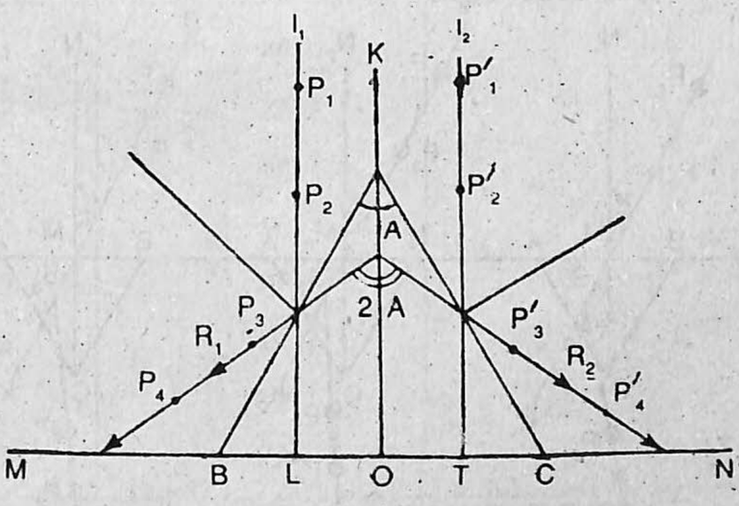


Fig. 27.2

(*i*) Take a sheet of white paper, fix it over a drawing board and draw a straight line MN as shown in Fig. 27.2 about 10 *cm* long. At the middle, put a mark 'O' on this line. Take two other marks L and T about 1 *cm* away on each side of the mark 'O'. Draw three lines perpendicular to the line MN from these points L, O and T.

(*ii*) Place the prism ABC in such a way that its base BC falls on the line MN and A falls exactly on the line KO.

(*iii*) Fix two pins P_1 and P_2 on the incident line I_1, these pins should be about 10 cm apart. Observe the *reflected* ray R_1 which comes after reflection from the face AB of the prism. Fix two more pins P_3 and P_4 *to exactly cover the images of pins* P_1 and R_2. Similarly fix pins on the incident line I_2 and locate the reflected ray R_2.

(*iv*) Remove the pins and join the marks left by the pins P_3, P_4 and P'_3 and P'_4 by sharp lines to meet at a point. Then the angle formed by the rays R_1 and R_2 as shown in Fig. 27.2 is equal to '2A'. Measure this angle by means of a Protractor and obtain the value of the angle 'A'.

(2) Angle of Minimum Deviation (D_m)

(*i*) Fix a white paper sheet over the drawing board. Draw a long line OO′. Take a number of points M_1, M_2, M_3,....etc., each about 10 cm apart. Draw perpendicular lines M_1N_1, M_2N_2, M_3N_3,...etc., from these points as shown in Fig. 27.3.

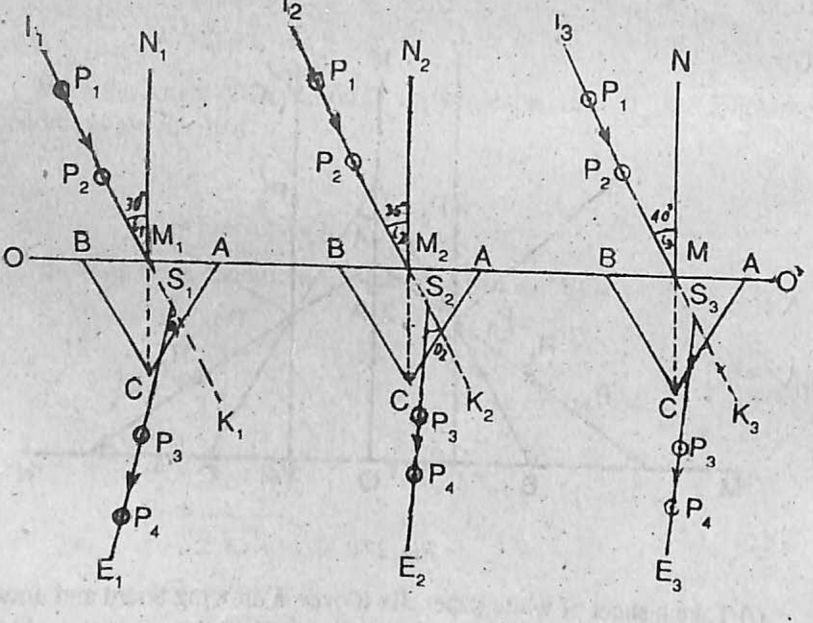


Fig. 27.3

(*ii*) Draw lines I_1 M_1, I_2 M_2, I_3 M_3,...etc., making angles of 30^0, 35^0, 40°....etc., respectively with the normals. Draw dotted lines M_1 K_1, M_2 K_2, M_3 K_3,...etc., by extending the incident lines.

(*iii*) Fix two pins P_1 and P_2 about 10 cm apart on the first incident line I_1M_1. Place the glass prism with its face AB coinciding with the line OO'. Locate the emergent ray E_1 looking through the face AC. Fix two pins P_3 and P_4 coinciding the images of pins P_1 and P_2. Remove the pins and draw a line joining the marks left by the pins P_3 and P_4 to obtain the emergent ray S_1E_1. Measure the angle $E_1S_1K_1$. This gives the angle of deviation D_1 for the angle of incidence i_1 (*i.e.*, 30°).

(*iv*) Repeat the experiment for seven other angles of incidence to get the values of angles of deviations $D_2, D_3, D_4, \ldots D_8$. Measure each angle and record your observations in the table given below :

Observations :

Room temperature = ...°C

Value of angle 2A = ...

∴ Refracting Angle of the glass prism A = ...

S. No.	Angle of incidence (*i*)	Angle of deviation (D)
1.	30°	
2.	35°	
3.	40°	
4.	45°	
5.	50°	
6.	55°	
7.	60°	
8.	65°	

(*v*) Select suitable scales to represent the angle of incidence (*i*) along the X-axis and angle of deviation (D) along the Y-axis and plot a graph. From this graph find the value of D_m as shown in Fig. 27·4.

(*vi*) Using the values of the Refracting Angle of the Prism (A) and angle of minimum deviation (D_m), calculate the value of the refractive index of the material of the prism by using equation (*vii*) given in theory above.

Graph :

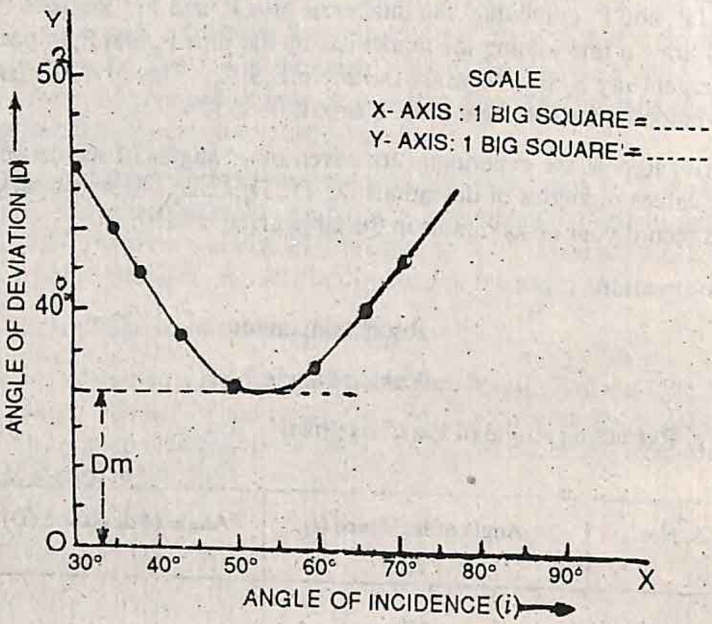


Fig. 27.4. (i—D) curve.

Calculations :

(*i*) Value of Angle of Minimum deviation from the graph = D_m = ...

(*ii*) $i = \frac{A + D_m}{2} = \text{..........}^0$

(*iii*) Value of Refracting Angle of the Prism = A = ...

Now
$$\mu = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

By calculation, $\sin\left(\frac{A + D_m}{2}\right) = a$ (say) = ...

and $\sin\left(\frac{A}{2}\right) = b$ (say) = ...

∴ Refractive Index of the glass prism

$$=\mu=\frac{a}{b}.$$

Result :

(*i*) The angle of minimum Deviation = ...

(*ii*) When ∠D is minimum then $i=\frac{A+D_m}{2}$

The refractive index of the glass prism with respect to air at .... ^{0}C = ...

Precautions :

(1) The face AB should always touch the line OO′

(2) An ink mark should be placed on the prism to distinguish the refracting angle A.

(3) The angle of incidence should not be less than 30^0.

(4) The pins should be placed at a large distance apart at not less than 10 to 15 cm.

(5) Pins should be fixed vertically and just after removing the pins encircle the pin pricks.

(6) Arrow-heads should be drawn to indicate the path of the incident, refracted and emergent rays.

(7) The curve should be smooth, passing through as many points as possible only.

ORAL QUESTIONS

Q. 1. *What is refraction of light?*

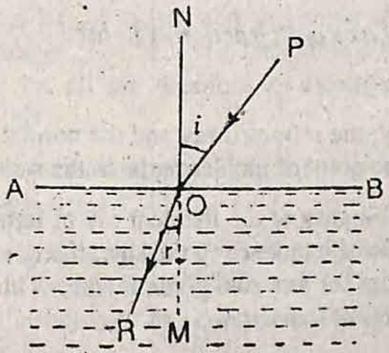


Fig. 27.5.

Ans. When a pencil of light passes more or less obliquely from the transparent medium into another, as, for instance, from air to glass, it undergoes a deflection from its straight path as shown in Fig. 27.5 which represents a ray of light passing from air into water. This change in direction of a ray of light is called *Refraction of light*, from a Latin word, meaning broken; for the ray is actually broken at the point O, where it enters into water.

The ray PO is called the *incident ray* and OR the *refracted ray*. The angle PON is called the *angle of incidence* and the angle ROM the *angle of refraction.*

Q. 2. *What are Refracting substances ? Give some examples.*

Ans. When a ray of light enters from one medium into another, it is in some cases, bent towards the normal, forming an angle of refraction, which is less than the angle of incidence as for example, when it passes from air into glass or water. In other cases, on the other hand, it is bent away from the normal and the angle of refraction is greater than the angle of incidence, as, for example, when it passes from glass or water into air. In the first case, the second medium is said to be more refracting than the first and, in the second case, less so. Among the most refracting substances are water, alcohol, ether and diamond. Gases in general are less refracting than water.

Q. 3. *What happens to a ray of light when it passes from (a) an optically rarer into an optically denser medium and (b) an optically denser into an optically rarer medium?*

Ans. (*a*) It bends towards the normal *i.e.*, the angle of refraction is less than the angle of incidence.

(*b*) It bends away from the normal *i.e.*, the angle of refraction is more than the angle of incidence.

Q. 4. *What are the Laws of Refraction of light?*

Ans. Laws of Refraction :

(*i*) The incident ray, the refracted ray and the normal to the surface of separation at the point of incidence, be in the same plane.

(*ii*) Whatever the obliquity of the incident ray of light, the ratio of the sine of the angle of incidence to the sine of angle of refraction is a constant quantity for any two given media. This is often spoken of as *Snell's Law of Refraction.*

Q. 5. *Define Refractive Index 'μ'.? What are its values for water, glass, diamond and air?*

Ans. Refractive Index (μ) of a medium for a particular colour of light is the ratio of velocity of light in vacuum to the velocity of light in that medium.

For all transparent solids and liquids, $\mu > 1$. Its value for water is 1·333 for crown glass 1·52 ; for flint glass 1·67 ; for diamond 2·47 and air 1·00.

Q. 6. *On what factors does the refractive index of a material depend?*

Ans. Refractive Index depends upon

(*i*) Nature of the material

(*ii*) Wavelength or colour of light

(*iii*) Temperature

(*iv*) Surrounding medium.

Q. 7. *Will the velocity of light be more in air or in glass?*

Ans. In air.

Q. 8. *What is a prism? What is angle of the prism?*

Ans. *A prism* is a portion of a transparent medium, bounded by two plane faces, inclined to each other at an angle. The angle between these two faces is called the *angle of the prism.*

Q. 9. *What is meant by the deviation produced by a prism? Is it same for all positions of the prism with respect to the incident ray of light?*

Ans. The angle through which the incident ray of light is deviated is called the Angle of Deviation. In fact it is the angle between the emergent ray and the incident ray produced.

The deviation produced in the path of an incident ray depends not only upon the material of the prism and the angle of the prism but *it also varies with the angle of incidence.* Thus deviation produced by a prism is not the same for all the positions of the prism with respect to the incident ray of light.

Q. 10. *Why does dispersion take place in a glass prism, while no such thing takes place in a glass slab?*

Ans. In a prism, light of different colours deviate to different extent as the velocity of different colours is different. Thus a beam of white light when refracted through a prism is dispersed to different colours.

The glass slab is presumed to be made up of two prisms of equal and opposite refracting angles. Thus light while getting dispersed by the first prism is recomposed by the second prism and hence no dispersion takes place.

Q. 11. *What is the nature of the graph between i and D? What is meant by minimum deviation position of the prism?*

Ans. The variations of the angle of deviation (D) with angle of incidence (*i*) are represented graphically in Fig. 27.4. It is obvious from the Fig. 27.4 that as the value of (*i*) increases, that of angle of deviation D decreases till for a particular value of angle of incidence, it attains a minimum value D_m. This angle of deviation D_m is called the *angle of minimum deviation.* When the prism is so placed with respect to the incident beam that the angle of deviation is minimum, then the prism is said to be in the position of minimum deviation.

Q. 12. *What is the speciality about minimum deviation?*

Ans. In this position the ray of light passes symmetrically through the prism *i.e.*, making the angle of incidence equal to the angle of emergence. For pure spectrum, the prism is set in the position of minimum deviation and we can also determine 'μ' of the material of the prism.

Q. 13. *Does the angle of minimum deviation depend upon the colour of light used?*

Ans. Yes, the deviation for different colours is different and so is their minimum deviation.

Q. 14. *If you place a pin at the bottom of a beaker of water. why does it appear to be raised?*

Ans. We see in the direction of the emergent ray of light, which when produced will give the apparent position of the pin, which will thus appear to be raised (Fig. 27·6).

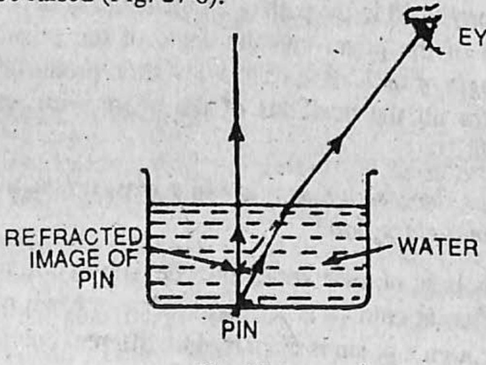


Fig. 27.6.

Q. 15. *What is total internal reflection of light?*

Ans. It is the phenomenon which a ray of light going from denser medium to rarer medium is reflected from the surface separating the two media.

Q. 16. *What is critical angle? How is it related to the refractive index?*

Ans. It is that angle of incidence in the denser medium for which the corresponding angle of refraction in the rarer medium is 90^0.

$$\mu = \frac{1}{\sin i_c}$$

where μ = refractive index

i_c = critical angle.

□ □

EXPERIMENT 28

To find the Refractive Index of a material given in the form of a Prism using a Spectrometer.

Apparatus :

1. Spectrometer.
2. Standard Source of Light (Sodium lamp).
3. Spirit level.
4. Prism.
5. Thermometer.
6. Reading lens.
7. Reading lamp.

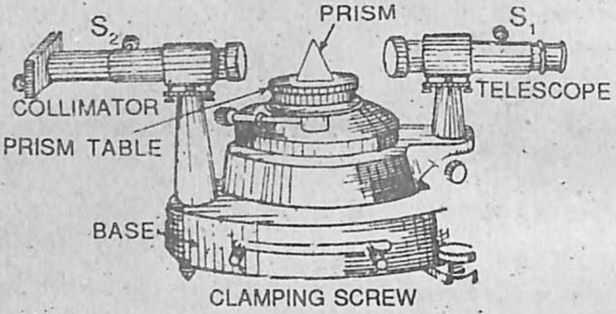


Fig. 28.1

Theory :

The refractive index μ of the material, in the form of a prism, is given by,

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

where A is the refracting angle of the prism and δ_m is the angle of minimum deviation for the light used.

The spectrometer is employed for finding the values of angles A and δ_m.

Spectrometer is an optical instrument with the help of which a pure spectrum can be obtained and studied conveniently. The spectrometer essentially consists of the following three parts as shown in Fig. 28.1.

1. The Telescope.
2. The Collimator.
3. The Prism Table with heavy base.

1. The Telescope :

The telescope consists of two lens systems, (1) the objective, (2) the eye-piece. Both the lens systems behave as convex lenses.

The objective is permanently fixed at one end of a metal tube and lies towards the prism table. The eye-piece is also carried in a metal tube which can slide in the tube carrying the cross-wires. The eye-piece is at the other end. The tube which carries the cross-wires can be moved in or out by means of rack and pinion arrangement using a screw S_1.

The telescope stands with the help of two screws on a small horizontal base; the base is on the upper end of a heavy arm which can be rotated concentric with the prism table. The two screws on which the telescope stands are there to make the telescope horizontal.

A clamping screw can clamp the telescope at any desired position and a tangent screw can then give a small displacement to the telescope. The angular movement of the telescope is noted with the help of two verniers V_1 and V_2, (diametrically opposite), which move over a main scale marked in degrees from 0 to 360 degrees.

2. The Collimator :

The collimator is the device for obtaining a beam of parallel rays from the source of light. It consists of a metal tube carrying an achromatic combination behaving as convex lens at the end towards the prism table. At the 2nd end of the metal tube is fitted a second metal tube carrying a fine-edge slit. The slit can be drawn in or out by rack and pinion arrangement using a screw S_2. The width of the slit can also be adjusted by means of another screw.

Like the telescope, the collimator also stands with the help of two screws on a small horizontal base ; the base is on the upper end of a heavy arm. The purpose of the two screws is to make the axis of collimator horizontal. Unlike the telescope, the collimator is permanently fixed and cannot be rotated.

3. The Prism Table :

It is a small circular metal disc carried over another metal frame with the help of three levelling screws. The lower frame can be raised or lowered and the prism table can be fixed at any desired height by means of a screw.

The prism table is attached to a large circular scale M marked in degrees. When the prism table is rotated the scale also rotates.

The prism table can be fixed by means of a clamping screw and a tangent screw can now give it a small angular displacement.

The main scale is generally carried over a heavy base.

There are marked some concentric circles and some parallel lines over the prism table which helps in the correct placing of the Prism.

Procedure :

Before any use can be made of the Spectrometer it has to be set for parallel rays.

(A) Setting of the Spectrometer :

The following is the order of the setting :

1. Setting of the Telescope.
2. Setting of the Collimator.
3. Setting of the Prism Table.

1. Setting of the Telescope :

(*a*) The telescope is first turned towards some white wall, the eye-piece is shifted with respect to the cross-wires till a sharp-image of the cross-wires is obtained. The eye-piece is now fixed with respect to the cross-wires.

(*b*) The telescope is turned towards some very distant object and the eye-piece as a whole is moved with the help of the screw S_1 till a sharp image of the distant object is obtained on the cross-wires. The telescope is now set for parallel rays. Its setting cannot be disturbed throughout the experiment.

2. Setting of the Collimator :

The spectrometer is mounted in front of the source of light so that the slit of the collimator is well illuminated by the source. The telescope is brought exactly in front of the collimator so that the rays coming from the collimator reach it. The slit is moved with the help of the screw S_2 till a sharp image of the slit is seen in the field of view of the Telescope. The width of the slit is now adjusted so that the image seen is a sharp line.

The axis of the telescope and that of the collimator are made to coincide so as to be horizontal. This is achieved with the help of the screws at the base of the telescope and the collimator so that the image of the slit is seen centrally in the telescope.

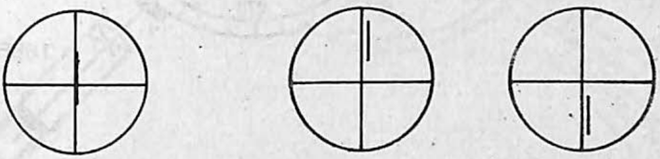


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Fig. 28.2

3. Setting of the Prism Table :

The prism table is first made perfectly horizontal with the help of the spirit level and the levelling screws. Its height is adjusted according to the size of the Prism. The prism table is then firmly clamped.

(A) Determination of the angle A of the Prism :

The Prism is mounted on the prism table as shown in Fig. 28.3 with the edge A at the centre of the prism table and the base BC perpendicular to the axis of the collimator.

The rays from the Collimator fall on the faces AB and AC of the prism from which these get reflected in the directions R_1 and R_2 (Fig. 28.3). The telescope is turned to receive the reflected rays R_1. The image of the slit is made to coincide exactly with the vertical cross-wire making use of the clamping screw and the tangent screw. The main scale readings and readings of the Verniers V_1 and V_2 are taken. The telescope is turned towards the right to receive the reflected rays R_2 and again the image of the slit is made to coincide exactly with the vertical cross-wire. The main scale readings and the readings of the Vernier scales are again noted. From these readings find 2 A, half of which will give the angle A.

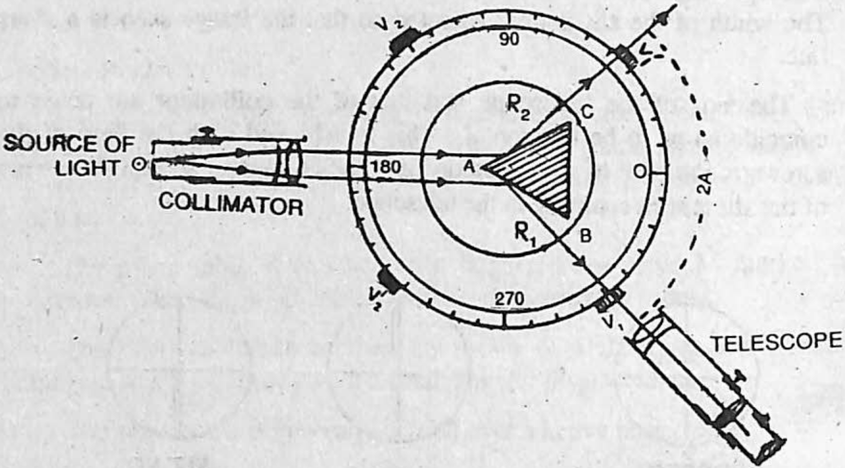

Fig. 28.3

(C) Determination of the Angle of Minimum Deviation δ_m.

Bring the telescope in front of the collimator, obtain the direct image of the slit in the Telescope without placing the prism. Coincide the image of the slit with the vertical cross-wire making use of the clamping screw and the Tangent screw. Note the main scale reading and the vernier V_1 and V_2 readings.

Place the prism centrally on the prism-table as shown in Fig. 28.4 so that the light incident from the collimator falls on the face AB. It gets dispersed into its constituent colours and the rays of different colours emerge from the face AC of the prism. Turn the telescope to receive these rays. Bring the ray of that particular colour in the field of view for which μ has to be found and coincide it with the vertical cross-wire.

Gradually rotate the prism table in the clockwise direction, the ray of particular colour will appear to turn in the anti-clockwise direction. A stage will, however, come when it will again start moving in the clockwise direction.

Coincide that particular position from which the ray just turns back with the cross-wire, adjusting with the help of the tangent screw. This is the position of minimum deviation since in this position the emergent ray has suffered the minimum deviation. Note the main scale reading and the Vernier V_1 and V_2 readings. Find the value of δ_m from these readings.

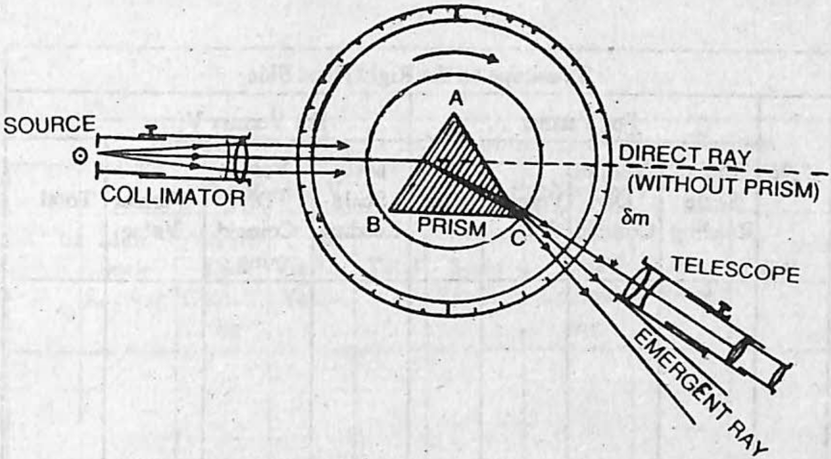

Fig. 28.4

Observations :

Smallest measurable value of the Main scale =

Least Count of the Scale =

For Angle A.

Telescope on the Left Hand Side								
S.No.	For Vernier V_1				For Vernier V_2			
	Main Scale Reading	Vernier Div. Coinciding	Vernier Value	Total	Main Scale Reading	Vernier Div. Coinciding	Vernier Value	Total
1								
2								
3								
Mean Value (say) a =					Mean Value (say) c =			

2.

Telescope on the Right Hand Side								
	For Vernier V_1				For Vernier V_2			
S.No.	Main Scale Reading	Vernier Div. Coinciding	Vernier Value	Total	Main Scale Reading	Vernier Div. Coinciding	Vernier Value	Total
Mean Value (say) $b =$					Mean Value (say) $a =$			

3. For angle δ_m

Telescope Receiving Direct Rays								
	For Vernier V_1				For Vernier V_2			
S.No.	Main Scale Reading	Vernier Div. Coinciding	Vernier Value	Total	Main Scale Reading	Vernier Div. Coinciding	Vernier Value	Total
Mean Value (say) $e =$					Mean Value (say) $f =$			

Telescope Receiving the Rays in Minimum Deviation Position								
S.No.	For Vernier V_1				For Vernier V_2			
	Main Scale Reading	Vernier Div. Coinciding	Vernier Value	Total	Main Scale Reading	Vernier Div. Coinciding	Vernier Value	Total
Mean Value (say) g =					Mean Value (say) h =			

Calculations : (1) For Angle 2 A.

From Vernier V_1 readings

$$2A = (360 + b) - a = k \quad \text{(say)}$$

From Vernier V_2 readings

$$2A = d - c = I \quad \text{(say)}$$

$$\therefore 2A = \frac{I+k}{2}$$

$$\text{And } A = \frac{I+k}{4} = \quad \text{....... (1)}$$

(2) For Angle δ_m

From Vernier V_1 readings

$$\delta_m = e - g = p \quad \text{(say)}$$

From Vernier V_2 readings

$$\delta_m = f - h = q \quad \text{(say)}$$

$$\therefore \delta_m = \frac{p+q}{2} = \quad \text{....... (2)}$$

Having found angles A and δ_m, substitute the values in the relation

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \ldots\ldots\ldots\ldots$$

Result :

The refractive index of the given material at °C is found to be = ...for.......colour (wavelength = 5893 A°)

Standard Value = ...

Error = ...%

Precautions :

1. The spectrometer must be set for parallel rays before use.
2. The reading of both the verniers should be taken.
3. The image must be made fine so that a sharp line image is seen.
4. The image must be made to coincide with the point of intersection of the cross-wires.
5. The prism must be placed in the correct position with the correct edge A at the centre of the prism table when measureing the angle A.

Exercise :

To determine the refractive index for the material of a prism for different colours of mercury light with the help of a spectrometer, and to calculate the dispersive power of the prism.

Hints : This experiment is but a repetition of the Expt. 28. Determine the angle of minimum deviation corresponding to each spectral line and calculate the refractive index separately in each case.

[For studying the variation of refractive index with wavelength of the spectral line employed, a graph can be drawn between the two quantities. From this study it will be seen that the value of refractive index increases as the wavelength diminishes.]

Now the dispersive power ω of the medium is given by

$$\omega = \frac{(\mu_v - \mu_r)}{(\mu - 1)}$$

where μ_v, μ_r and μ are the refractive indices of the three chosen wavelength in the violet, red and yellow region respectively.

EXPERIMENT 29

To determine the refractive index of a liquid for a given wavelength of light with a spectrometer.

Apparatus :

Same as in Expt. 28 except a *thin-walled hollow glass prism* (*optically true*) instead of a solid glass prism is required.

Theory :

Same as in Expt. 28.

Procedure :

Same as in Expt. 28.

Observations :

Same as in Expt. 28.

Calculations :

Same as in Expt. 28.

Precautions :

Same as in Expt. 28.

◆

EXPERIMENT 30

To make a simple double slit and find the wavelength of red light by it.

Apparatus :

Straight filament lamp (12V, 24W); microscope slide; razor blades; travelling microscope; paint brush with fine bristles; paste of colloidal graphite and water; Retort stand; ruler; magnifying glass; filters (Red, green, blue).

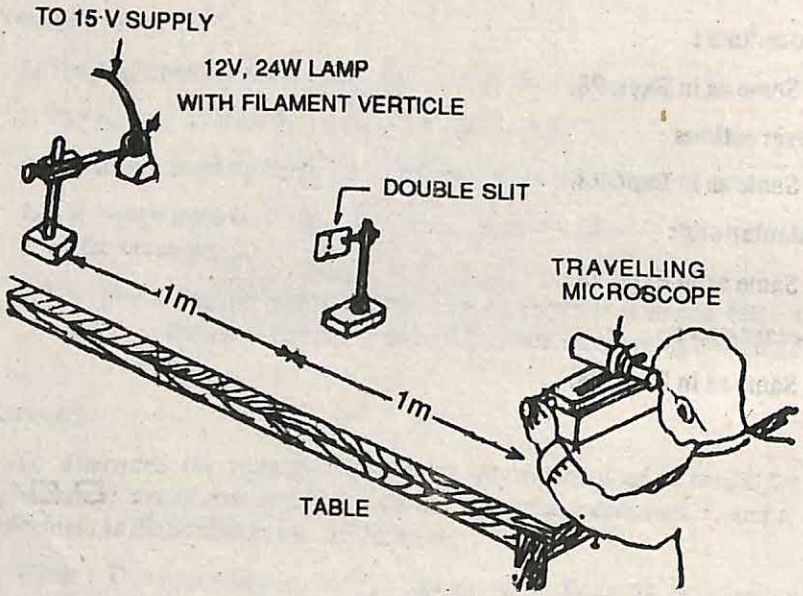

Fig. 30.1

Theory :

Interference occurs when waves from two coherent sources cross. Such sources produce waves having the same frequency, equal or comparable amplitudes and a phase difference that does not alter with time.

The wavelength of light must be *small* otherwise the diffraction effects it gives would be more evident than they are. In order to obtain interference fringes sufficiently far apart to be seen, we must have

(*a*) the sources very close together.

(*b*) the screen (or eyepiece) as far as possible from the sources. Also if the sources are to be *coherent*, they must be derived, in practice, from the same source. To obtain two coherent wave trains from a point of a single source, one of the two methods is adopted :

(*i*) *division of wavefront* as is done in *Young's double slit*, Fresnel's biprism and Lloyd's mirror, and

(*ii*) division of amplitude, usually by partial reflection and transmission at a boundary, as occurs in *Newton's rings and in *wedge fringes.

One of the first to demonstrate the interference of light by double slit was Thomas Young in 1801. The principle of his method is shown in Fig. 30·2.

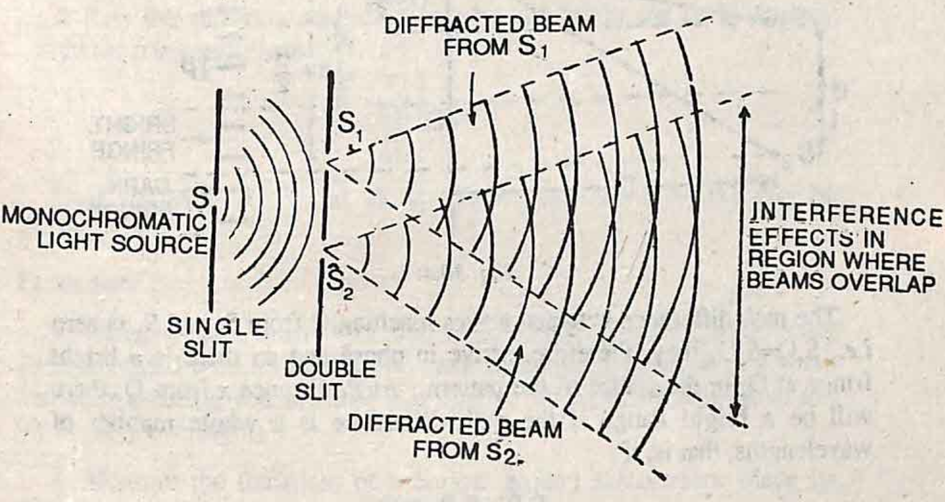
DIFFRACTED BEAM FROM S_1
S_1
S
MONOCHROMATIC LIGHT SOURCE
S_2
SINGLE SLIT
DOUBLE SLIT
DIFFRACTED BEAM FROM S_2
INTERFERENCE EFFECTS IN REGION WHERE BEAMS OVERLAP

Fig. 30.2.

Monochromatic light (*i.e.*, of one colour) from a narrow vertical slit S falls on two other narrow slits S_1 and S_2 which are very close together and parallel to S. S_1 and S_2 act as two coherent sources (both being derived from S) and if they are narrow enough, diffraction causes the emerging beams to spread into the region beyond the slits. Superposition occurs in the shaded area of Fig. 30.2, where the diffraction beams overlap. Alternate bright and dark equally spaced vertical bands (Interference fringes) can be observed on a screen or at the cross-wires of an eyepiece (Fig. 30.3). If either S_1 or S_2 is covered the bands disappear.

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*Consult your teacher.

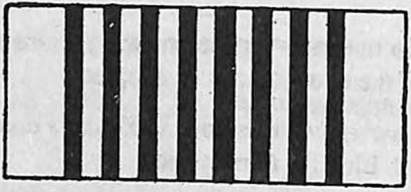


Fig. 30.3.

An expression for the separation of two bright (or dark) fringes can be obtained from Fig. 30·4.

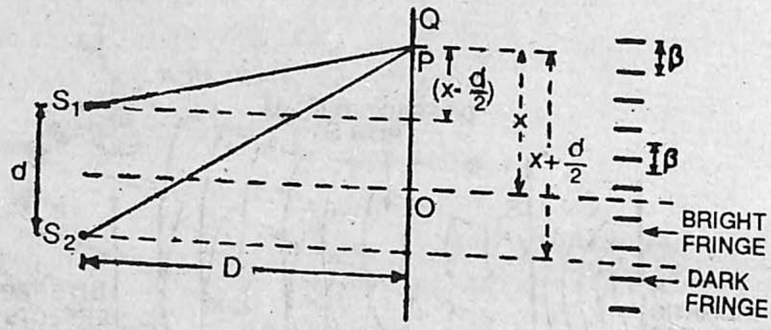


Fig. 30.4.

The path difference between waves reaching O from S_1 and S_2 is zero *i.e.*, $S_1O=S_2O$, they, therefore, arrive in phase and so there is a bright fringe at O, in the centre of the pattern. At P, distance x from O, there will be a bright fringe if the path difference is a whole number of wavelengths, that is, if

$$S_2P - S_1P = n\lambda$$

where n is an integer (or zero) and λ is the wavelength of the light. We say the nth bright fringe is formed at P.

If D is the distance from the screen or cross-wire to the double slit and 'd' is the slit separation. Hence

$S_2P^2 - S_1P^2 = 2dx$

But $S_2P^2 - S_1P^2 = (S_2P - S_1P)(S_2P + S_1P)$

In practice, d is very small (*e.g.*, 0·5 mm) compared with D (*e.g.*, 1 *m*) and if P is near O then S_2P and S_1P are each just greater than D. Therefore, we can say $(S_2P + S_1P) \doteq 2D$. It follows that

$$(S_2P - S_1P)\,2D = 2dx$$

$$\therefore \quad S_2P - S_1P = \frac{2xd}{2D} = \frac{xd}{D}$$

For the *n*th bright fringe at P we have

$$n\lambda = \frac{dx}{D} \qquad \text{......(1)}$$

If the next bright fringe *i.e.*, the $(n+1)$th, is formed at Q where OQ = x' then

$$S_2Q - S_1Q = (n+1)\lambda$$

$$(n+1)\lambda = \frac{dx'}{D} \qquad \text{......(2)}$$

Subtracting (1) from (2) we get

$$\lambda = \frac{d(x' - x)}{D}$$

If β is the distance between two adjacent bright (or dark) fringes, called the *fringe width*, then $\beta = (x' - x)$ and so

$$\boxed{\lambda = \frac{d\beta}{D}} \qquad \text{......(3)}$$

Thus knowing d, β and D; the wavelength of light (λ) can be determined.

Procedure :

1. Using a paint brush with fine bristles, one side of a microscope slide is coated with a smooth, thin paste of colloidal graphite and water and after assuring yourself that it is *opaque* to light, set it aside to dry (preferably overnight).

2. Measure the thickness of a hollow ground safety razor blade by measuring the thickness of a pile of (say) 10 blades.

3. When the slide is dry draw two lines on it by holding two *razor blades tightly together and drawing them along a ruler on the slide.

[*You will probably have to do this several times before you produce two lines of equal thickness. Start at one end of the slide and work across. Examine these lines with a magnifying glass and choose the best pair.*]

---

* A ball-point pen with a fine ball point will also serve the purpose. *A blunt needle, or pin is not quite so easy to handle.* A darning needle, with the end of its eye broken off can be used as an ingenious tool to rule both slits at once; but this is not recommended for general use.

4. Find the distance between the lines by means of a travelling microscope. This would give the slit separation '*d*'.

5. Take a lamp with a line filament. A 24 watt 12 volt lamp over run does well. The 100 watt tungsten-iodine lamp in the compact light source is also very good for this.

Shield the lamp so that no stray light reaches the observer. It is also very important to avoid illumination by light reflected by the surface of the table. (Any fairly smooth surface becomes an excellent mirror at very oblique incidence). It is necessary to instal limiting screens and place black cloth on the table to prevent that.

Filters can be used to obtain coloured light from a white light source *e.g., cover the lamp with green filter in order to estimate the wavelength of green light.*

6. Set up the apparatus in a *dark room* as shown in Fig. 30.1. At least a metre should be allowed between the lamp and the slits, and one to several metres from the slits to the travelling microscope.

[*Ask your teacher to help you to orient the slits parallel to the filament of the lamp since this is an important adjustment for obtaining clear fringes.*]

7. View the fringes (in the dark room) at the cross-wire of a travelling eyepiece (*e.g.*, a travelling microscope with the objective removed).

Seeing the fringes—'light + light' making 'more light' in some places but making 'no light' in other places—is the most important thing.

8. Find the average fringe width β by measuring across as many fringes as possible with the travelling eyepiece.

For this purpose it is a good plan to begin the measurement at one edge of the field of view.

Set the cross-wire accurately down the *centre* of the first bright fringe, and *move it always in one direction* by means of the screw giving the transverse motion, stopping at every two or three fringes to note the position. From these readings deduce the distance (β) between the consecutive fringes.

9. Measure the distance (D) between the double slit and the plane of the cross-wires by using a metre-rule.

10. Now calculate the wavelength (λ) of the light used with the help of the formula

$$\lambda = \frac{d\beta}{D}.$$

Observations :

(A) *Readings for the determination of 'd'*

Pitch of the screw = ...cm

No. of divisions on the vernier scale = ...

∴ Least count of the screw = ...cm

S. No.	Microscope reading		Slit separation
	1st slit	2nd slit	
1.	.....cm	.....cm	.....cm
2.			
3.			
4.			

Mean = *d* = ...*cm*

(B) *Readings for the determination of* β

No. of fringe	Microscope reading (*a*)	No. of fringe	Microscope reading (*b*)	Separation for 10 fringes (*b*)—(*a*)
1	......cm	11	....cm	.....cm
3		13		
5		15		
7		17		
9		19		
...		...		
...		...		
...		...		

Mean separation for 10 fringes = ...cm

∴ Mean separation for 1 fringe = β = ...cm

(C) Distance between the double slit and the eyepiece = D = ...cm

Calculations :

(*i*) d = ...cm

(*ii*) D = ...cm

(*iii*) Mean fringe width β = ...cm

$$\therefore \quad \lambda = \frac{d}{D}\beta = \text{.....cm}$$

$$= \text{.....A}^{\circ}$$

Result :

The value of the wavelength of ....light = ...cm

= ....A°

Standard value = ...cm.

∴ Error = ... = ...%.

Precautions and Sources of Error :

(*i*) The slits should not be too far apart or too wide because the central maxima of the diffraction patterns may not overlap and no fringes will be seen.

(*ii*) Place a ruler across the coated slide and run the blades along the edge of the ruler to make slits. Make many pairs of slits and then choose the best.

(*iii*) The slits should be made parallel to the filament of the lamp and to the vertical cross-wire of the eyepiece.

(*iv*) While taking measurements for the fringe width *the vertical cross-wire should be set in the centre of a bright fringe only.*

(*v*) While using the micrometer screw of the travelling microscope, back-lash error should be avoided.

(*vi*) The chief source of error lies in a faulty adjustment of any of the components of the apparatus. *If the adjustment is slightly defective, the observed fringe width will always be less than the true fringe width.*

Q. 1. *On what principle is this experiment based?*

Ans. It is based on the Interference of Light.

Q. 2. *What do we mean by "Interference of Light"?*

Ans. With a single source of disturbance, the distribution of energy in the surrounding medium is uniform but when there are two adjacent sources giving out continuous waves of the same wavelength and amplitude and having the same phase or a constant difference in phase, the distribution of energy is no longer uniform. At some points where the crest of one wave falls upon the trough of other and vice versa, the resultant amplitude is reduced to zero and the energy is minimum. While at other points where the crest of one wave falls upon the crest of the other or trough of one falls upon the trough of the other, the resultant amplitude is increased and the energy becomes maximum. *This modification in the distribution of light energy obtained by the superposition of two or more waves is called interference of light.*

Q. 3. *What is principle of superposition?*

Ans. When two or more sets of waves pass through and cross one another in the *same* medium they behave as if the other were not present, that is, the effects produced by one are totally independent of the effects due to the other. The resultant displacement, at any instant, of a particle depends upon the phase difference between the waves and is the *algebraic* sum of the displacements it would have at the same instant due to each separate set. This is known as the *principle of superposition.*

Q. 4. *Are there any conditions for observing interference of light? If so, what?*

Q. 5. *What are such sources known?*

Q. 6. *How can we obtain coherent sources?*

Q. 7. *How have you been able to procure coherent sources in your present experiment?*

Q. 8. *Will it not be possible to obtain interference effects from two exactly identical lamp filaments (or candles) set side by side?*

Q. 9. *What is the lamp you are using here?*

Q. 10. *Is sodium lamp really indispensable?*

Q. 11. *Will we get interference effect if we replace the sodium lamp by an electric glow lamp?*

Q. 12. *Why should we expect only a few fringes in this case?*

Q. 13. *In this coloured fringe pattern which colour will appear first the red or the violet one? Why ?*

Q. 14. *What will be the colour of the central fringe in this case? Why?*

Q. 15. *What are the factors which govern the fringe width in this experiment?*

Q. 16. *Why it is necessary to make the slit narrow ? Will broad slit not do?*

Q. 17. *How do you measure fringe width?*

Q. 18. *Do you take any precaution in moving the screw head?*

Q. 19. *What adjustment do you make with the eyepiece?*

□ □

SECTION C

SOME SUGGESTIVE PROJECTS

(One Investigatory Project to be done)

Note to the Students

Since these are open ended projects so there is no single procedure for doing these projects. These projects require *intensive* reading of the modern literature on the topic concerned, constructive thinking, intelligence, good planning; scientific imagination; skill to improvise apparatus etc. Make your project probing and challenging so that you may thoroughly understand the concepts involved. Inculcate in yourself the skills of collecting data and applying the knowledge gained. That will help you to gain confidence and reinforcing your command of the subject.

As an illustration some sample Projects are explained. It is requested *not to follow these blindly*. Do improve upon these projects and attack them from different angles if possible.

The following pattern is suggested for proceeding with the Project :

(*i*) Problem
(*ii*) Introduction
(*iii*) Scope
(*iv*) Planning
(*v*) Setting and Execution
(*vi*) Presentation of Data
(*vii*) Conclusion
(*viii*) Discussion
(*ix*) References.

Illustrative list of Projects :

1. A study of tensile strength of fibres.
2. A study of fluid flow relating to Viscosity and Bernoulie's principles.
3. A study of the rate of cooling of the liquids in different situations.
4. A study of the velocity of sound in different media using ultrasonic waves and Kundt's tube.
5. A study of reflection, refraction, interference; and diffraction of mechanical waves by using a "Ripple tank".
6. Construction of an ultrasonic thief detector.

7. A study of the magnetic elements of earth in a school laboratory.
8. Use of C.R.O. to study the characteristic of wave forms.
9. Construction of an electrical measuring instrument using magnets and copper wire.
10. Construction of a thermocouple thermometer and calibrating it using sensitive instruments.
11. Use of vacuum tubes/semiconductors in construction of amplifier/oscillator/receiver/voltage stabilizer.
12. A study of the electric grant illustrating basic principles of automation as in assembly of switching flasher relay circuits using photocells and thermo elements.
13. A study of the magnetic field produced by passage of electric current through an improvised coil.
14. Construction of a transformer and to study its characteristics.
15. Any other project with the approval of the teacher (involving 15 hours work).

□ □

SAMPLE PROJECT 1

Aim :

A study of the Magnetic field produced by passage of Electric current through an improvised Coil.

Apparatus :

(*i*) A set of improvised Coils.
(*ii*) Ammeter.
(*iii*) Battery or accumulator.
(*iv*) Rheostat.
(*v*) Spirit level.
(*vi*) Reversing Key or a Commutator
(*vii*) A plug key.
(*viii*) Sand Paper and Connecting wires.

Theory :

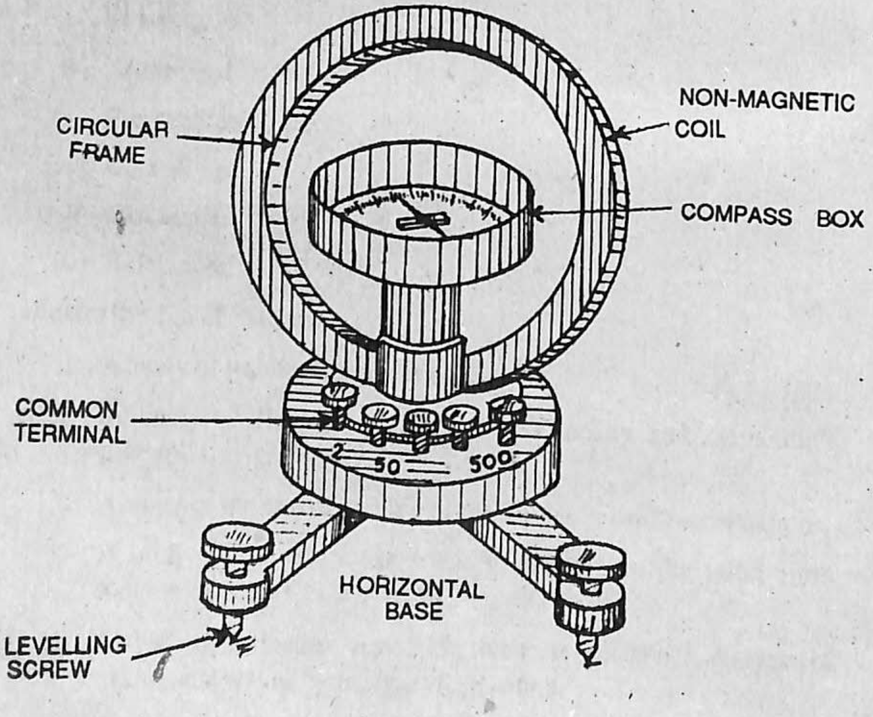


Fig. P 1.1 Improvised Coil.

The improvised coil consists of a non-magnetic (wooden) circular frame on which are wound many sets (four or five) of coil of insulated copper wire. The ends of these sets of coils are connected to the binding screws, fixed to the base-board of the instrument. One terminal is common to all the coils. The whole wooden circular frame is free to be rotated about its vertical axis. One coil consists of *two* turns of thick copper wire for use with strong currents, and the other coils consist of 10, 20, 50 and 100 turns respectively of thin copper wire. There is a compass box fixed on the vertical axis in such a way that its small magnetic needle, free to rotate in the horizontal plane, lies exactly at the common centre of the vertical coils.

If a current of '*I*' units be flowing through '*l*' length of wire bent into an arc of '*r*' radius, the magnetic field intensity (F) at the centre of the arc is given by

$$F = \frac{\mu_0}{4\pi} \cdot \frac{Il}{r^2}$$

where $\mu_0 = 4\pi \times 10^{-7}$ weber per ampere-metre and is known as the permeability of free space.

If the wire forms one complete circle, $l = 2\pi r$, hence

$$F = \frac{\mu_0}{4\pi} \quad I \cdot \frac{2\pi r}{r^2} = \frac{\mu_0 I}{2r}$$

For a circular coil carrying *n* turns

$$F = \frac{\mu_0 I n}{2r} \qquad \ldots(i)$$

If the current '*I*' is in amperes, then

$$\boxed{F = \frac{\mu_0 I n}{2r}} \qquad \ldots(ii)$$

It is clear from equation (*ii*) that

$$F \propto n$$

$$\propto I$$

In order to study the effect of '*n*' and '*I*' on the magnetic field intensity F, the improvised coil is placed in the magnetic meridian, the magnetic field due to the current 'I' flowing in the coil is perpendicular to H, the horizontal component of earth's magnetic field, and consequently the magnetic needle placed at the centre of the coil is acted upon by two uniform magnetic fields F and H which are at right angle to each other. Let the magnetic needle make an angle θ with H in the equilibrium position (Fig. P. 1.2). According to the Tangent Law :

$$F = H \tan\theta \qquad \ldots(iii)$$

or

$$\frac{\mu_0 I n}{2r} = H \tan\theta \qquad \ldots(iv)$$

Since 'H' is constant at the place of experiment, we have

$$\tan\theta = \frac{\mu_0 n I}{2rH} = \frac{2\pi n I}{rH} \cdot 10^{-7} \qquad \ldots(v)$$

Thus the magnetic field intensity F (tan θ is a measure of F) at the centre of the coil is directly proportional to the number of turns (*n*) if the current 'I' is kept constant and F is also directly proportional to the current I if the number of turns (*n*) is kept constant.

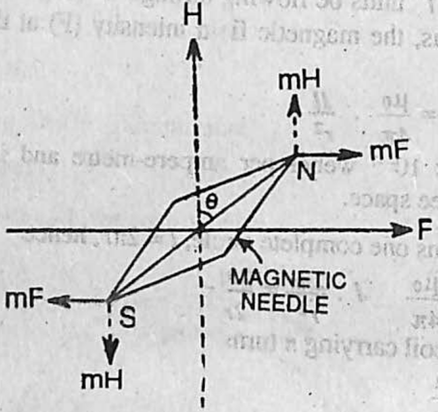


Fig. P. 1.2. Tangent Law.

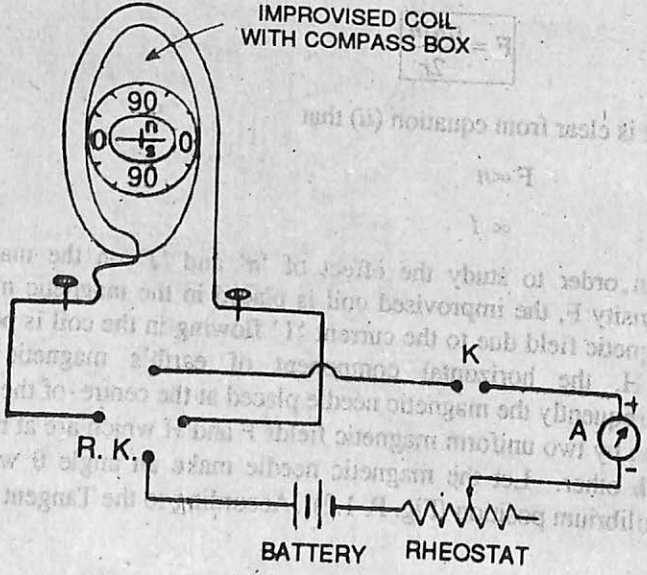


Fig. P. 1.3. Scheme of Connections

Procedure :

1. Draw a circuit diagram showing the scheme of connections as shown in Fig. P. 1.3.

Setting of Improvised Coil :

2. Keep the improvised coil on the table at a large distance from the other apparatus so that *there is no magnetic substance in its vicinity.* Level the base of the coil with the help of a spirit level and the levelling screws.

3. By placing the eye a little above the coil, rotate the instrument in the horizontal plane in such a way that the coil, the magnetic needle and its image in the plane mirror, placed below the needle in the compass box, all lie in the same vertical plane. This adjustment puts the coil roughly in the magnetic meridian.

Hold strongly the frame of the coil in this position and rotate the compass box till the long aluminium pointer, which is at right angles to the magnetic needle, reads 0—0 on the circular scale. Gently tap the box to see that the magnetic needle rotates freely.

Test of Setting :

4. Now to adjust the coil *exactly* in the magnetic meridian make the electrical connections as shown in Fig. P. 1.3. Connect the coil (say 50 turns) to the battery, a rheostat, a one way key (K) and an ammeter (A) through a reversing key (R.K.).

With the help of rheostat adjust the current in the coil so that the deflection in the magnetic needle is of the order 45° — 60°. After lightly tapping the glass cover of the compass box with finger, note the deflection at the two ends of the aluminium pointer. Then reverse the current in the coil with the help of the reversing key (R.K.), and again note the deflection as before. If the mean deflection in the two cases does not agree closely, the coil is not in the magnetic meridian. Slightly turn the coil and repeat the process until the mean deflections with the direct and reverse currents agree as closely as possible.

Variation of F with Current I :

5. (*i*) Connect one of the coils say coil of 100 turns in the circuit. Pass the current in the circuit and adjust the rheostat so that the magnetic needle shows a deflection of about 40°. Read the ammeter and also note readings at both the ends of the aluminium pointer.

(*ii*) Reverse the direction of the current in the coil with the help of reversing key (R.K.) and note the readings of aluminium pointer again. Take the mean of four deflections.

(*iii*) Increase the current in the coil by adjusting the rheostat such that the deflection increases to 45° and again take four readings and their mean value as explained in steps (*i*) and (*ii*).

(*iv*) Now go on increasing the current through the coil so that the deflection increases in step of 5 degree and find out the mean value of deflections in each case. Care should be taken that the deflection should not exceed 60°.

(*v*) Plot a graph taking current '*I*' along X-axis and tan θ along the Y-axis where θ is the mean of four deflections. This curve should be a straight line (Fig. P. 1.4).

6. Variation of F with the number of turns (n) :

(*i*) Connect the coil of 2 turns in the circuit and adjust the rheostat so that the deflection is of the order of 30°—60°. Read both the ends of the aluminium pointer both for direct and reverse currents. Also note the reading of the ammeter and *this current is not to be changed throughout for this part of the experiment.* Take the mean of the four deflections so taken.

(*ii*) Now connect the next coil of 10 turns in the circuit and adjust the rheostat if necessary so that the ammeter shows the *same current* as above. Read again both the ends of the aluminium pointer both for direct and reverse currents and take the mean value of the four deflections.

(*iii*) Repeat the above mentioned step for other coils of turns; 20, 50 and 100, keeping *the same current* throughout the coils of these turns as for 2 turns and 10 turns coils. Take the mean of four deflections in each case.

(*iv*) Plot a graph taking number of turns (*n*) along X-axis and tan θ along the Y-axis where θ is the mean deflection in each case. This curve should be a straight line (Fig. P. 1.5.).

Observations and Calculations :

Least count of the ammeter = ...A

Zero reading of the ammeter = ...A

(*i*) **Variation of F with I.**

Number of turns of the coil = ...

S. No.	Corrected Current (I) in amperes	Deflection of the pointer for				Mean deflection (θ) in degrees	tan θ
		Direct Current		Reverse Current			
		One end of the pointer	Other end of the pointer	One end of the pointer	Other end of the pointer		
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							

Graph :

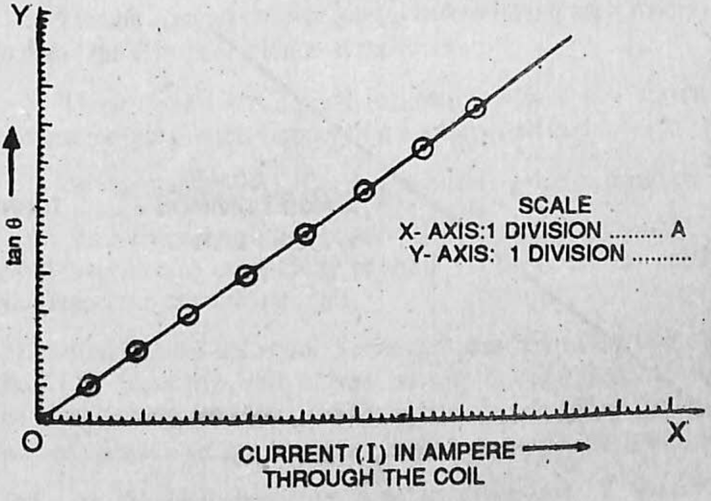


Fig. P.1.4. Variation of F with I for a coil of 100 turns

(*ii*) Variation of F with n :

Constant Corrected reading of ammeter = ...A

S. No.	Number of turns of the coil used (n)	Deflection of the pointer for				Mean deflection (θ) in degrees	tan θ
		Direct Current		,Reversed Current			
		One end of the pointer	Other end of the pointer	One end of the pointer	Other end of the pointer		
1.	2						
2.	10						
3.	20						
4.	50						
5.	100						

Graph :

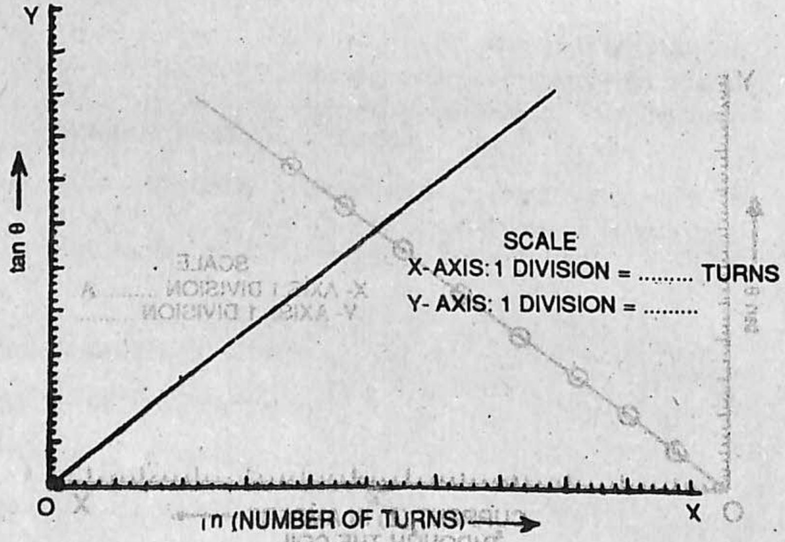


Fig. P.1.5. Variation of F with n for the same current

Result :

1. The graph between the current (I) and tan θ is a straight line showing that $F \propto I$.

2. The graph between the number of turns (n) and tan θ is a straight line indicating that $F \propto n$.

Precautions :

1. Before making connections, always draw the circuit, get it approved by the teacher and seek his permission for the connection.

2. Clean the ends of the connecting wires with sand paper. The connections should be clean and tight.

3. Always use a key in the battery circuit and remove the plug of the key while making connections as well as after each reading is taken.

4. The positive marked terminal of the ammeter should always be connected to the positive pole of the battery.

5. The connecting wires should be straight and not coiled in order to eliminate the effect due to self-induction.

6. The base of the improvised coil and compass box should be carefully levelled so that the plane of the coil becomes vertical and the needle is free to swing in the horizontal plane.

7. After placing the improvised coil exactly in the magnetic meridian, the positions of the levelling screws should be marked on the table.

8. Tap the compass needle gently before taking each reading in order to avoid the effects of friction at the pivot.

9. There should not be any magnetic material and current bearing conductors lying in the vicinity of the improvised coil.

10. While reading the deflection, avoid error due to parallax.

11. Both the ends of the pointer in the compass box should be read to avoid error due to eccentricity of the pivot on which the needle rotates with respect to the circular scale.

12. Readings of deflection in the compass box of the improvised coil should be taken first with current passing in one direction and then by reversing it to avoid errors due to thermo-electric effects and due to any want of accurate setting of the coil in the magnetic meridian.

13. All the readings should be adjusted between 25° and 65° because accuracy is maximum when the deflection is around 45° for then the readings of deflection would be least liable to error.

Sources of Error :

(*i*) The coil may not be exactly circular and the needle may not be situated exactly at its centre.

(*ii*) The plane of the coil may not be exactly in the magnetic meridian.

(*iii*) The magnetic needle is not *very small* so that it does not move in a uniform magnetic field at the centre, hence the tangent law is not accurately obeyed.

(*iv*) The friction at the pivot may not be totally absent.

□□

SAMPLE PROJECT 2

CONSTRUCTION OF A THERMO-COUPLE AND ITS CALIBRATION and then determination of the e.m.f. in microvolts of the thermocouple for various temperature differences between the junctions.

Apparatus :

Different material wires (say iron, copper), Potentiometer, 2 volt accumulator; plug key; tapping key; two way key; two resistance boxes (each 0—1000 ohms); sliding contact; Daniell cell; Standard cadmium cell of constant *e.m.f.* 1.0183 volts; fixed resistor of at least 10,000 ohms; Sensitive galvanometer (preferably reflecting type) with centre zero and sensitivity control; Ice—not essential but desirable; thermometer (0° — 100° C); thermometer (0° - 360° C or higher if available). Arrangement to have high temperature (600 W bowl type electric fire). If electrical heater is not available then an engine-oil bath can be used; soldering equipment; Test tube; Mica Discs ; Cork; Fire clay Test tubes.

Details of the Thermocouple and the heater :

Clean the ends of a piece of iron wire, 80—100 cm long and then to each one solder a length of copper wire, also cleaned at the ends.

In a cylinder of brass, of diameter 2·5 cm and of length 5 cm; drill two holes, one of the diameter 0.4 cm and the other of diameter 0.8 cm as

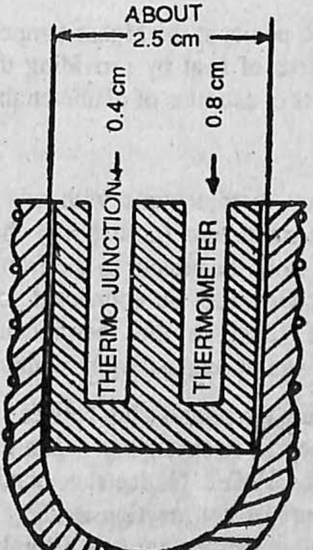


Fig. P. 2.1

shown in Fig. P. 2·1. These holes are to take one of the thermojunctions and the thermometer respectively. Before drilling the second make sure that 0·8 cm is sufficient to take the thermometer (0° — 360°C) which you will be using. Mount this brass cylinder in the heating element of a 600 —watt bowl type electric wire as shown in Fig. P. 2·1. Into the smaller of the two holes introduce one of the thermojunctions and fix the other one in a test tube by means of a cork through which the thermometer (0 —100°C) passes as shown in Fig. P. 2·2.

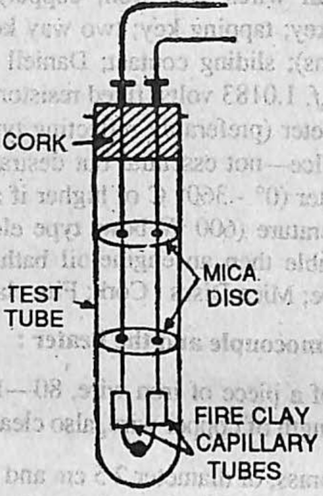


Fig. P. 2.2

To obtain balance points at the higher temperatures, it is necessary to reduce the rate of loss of heat by providing the heater with a suitable screen *e.g.*, a cylinder of asbestos of diameter about 8 cm.

Theory :

For a Copper-Iron thermocouple with one junction at 0°C and the other at a higher temperature (upto 570°) the *e.m.f.* is such that the current would flow from the copper to the Iron through the hot junction. Thus the cold junction must be connected to the positive end of the potentiometer wire (imagine the thermocouple replaced by a cell connected so that it would send a current in the same direction).

The curve showing the relationship between the temperature of the hot junction and the thermo-electric *e.m.f.* when the cold junction is kept at 0°C, is given in Fig. P. 2·3. Notice that maximum *e.m.f.* is obtainable when the temperature of hot junction is 285°C. The *e.m.f.* falls to zero again by 570°C, and in fact the curve is a parabola symmetrical about the ordinate corresponding to 285°C. This important temperature is known

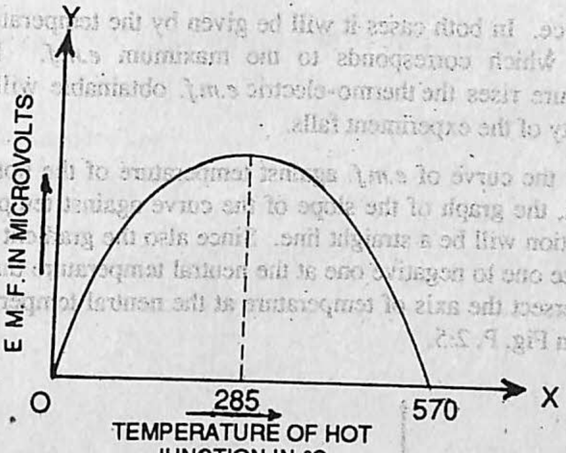


Fig. P. 2.3

as the *neutral temperature* and is a constant for a given pair of metals. It should be understood that it is *not* the difference in temperature between the junctions required to produce maximum *e.m.f.* but is a temperature *for the hot junction* at which maximum *e.m.f.* is produced. This will be better understood if Fig. P. 2.4 is examined. Here the thermo-electric *e.m.f.'s* are plotted against the temperatures of the hot junction with the changed condition that the cold junction is no longer at 0°C but at, say 15°C. This curve is obtainable from Fig. P. 2.3 by sliding the temperature axis upwards until it intersects the parabola at the 15°C mark

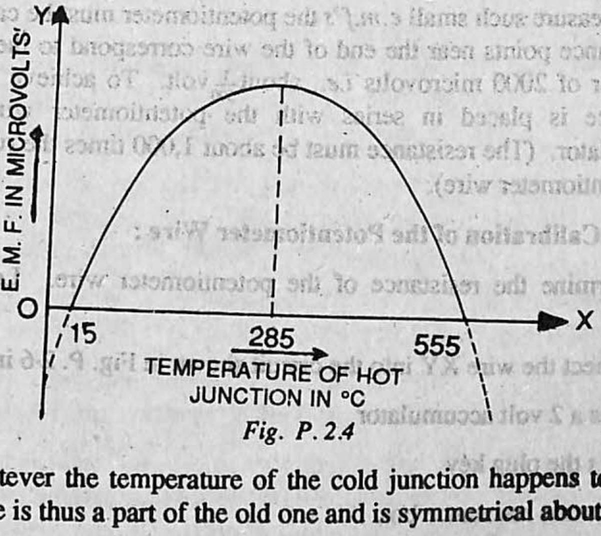


Fig. P. 2.4

—or whatever the temperature of the cold junction happens to be. The new curve is thus a part of the old one and is symmetrical about the same line.

Experimentally it is just as simple to find the neutral temperature when the cold junction is kept at room temperature as when it is kept in melting ice. In both cases it will be given by the temperature of the hot junction which corresponds to the maximum *e.m.f.* But as room temperature rises the thermo-electric *e.m.f.* obtainable will fall *i.e.*, the sensitivity of the experiment falls.

Since the curve of *e.m.f.* against temperature of the hot junction is a parabola, the graph of the slope of the curve against temperature of the hot junction will be a straight line. Since also the gradient changes from a positive one to negative one at the neutral temperature this straight line will intersect the axis of temperature at the neutral temperature. This is shown in Fig. P. 2·5.

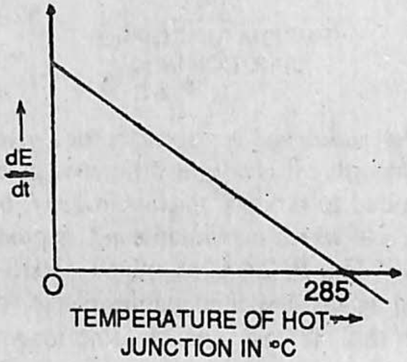


Fig. P. 2.5

To measure such small *e.m.f.'s* the potentiometer must be calibrated so that balance points near the end of the wire correspond to the *e.m.f's* of the order of 2000 microvolts *i.e.*, about $\frac{1}{500}$ volt. To achieve this a high resistance is placed in series with the potentiometer wire and the accumulator. (The resistance must be about 1,000 times the resistance of the potentiometer wire).

Part I. Calibration of the Potentiometer Wire :

Determine the resistance of the potentiometer wire. Let it be '*r*' ohms.

Connect the wire XY into the circuit shown in Fig. P. 2·6 in which

B is a 2 volt accumulator

K_1 is the plug key

R_1 is one resistance box

R_2 is the other resistance box

XY is the potentiometer wire

C_1 is the Daniell cell

C_2 is the standard cadmium cell with its high resistor, R

K_2 is the two-way key

K_3 is the tapping key

G is the galvanometer.

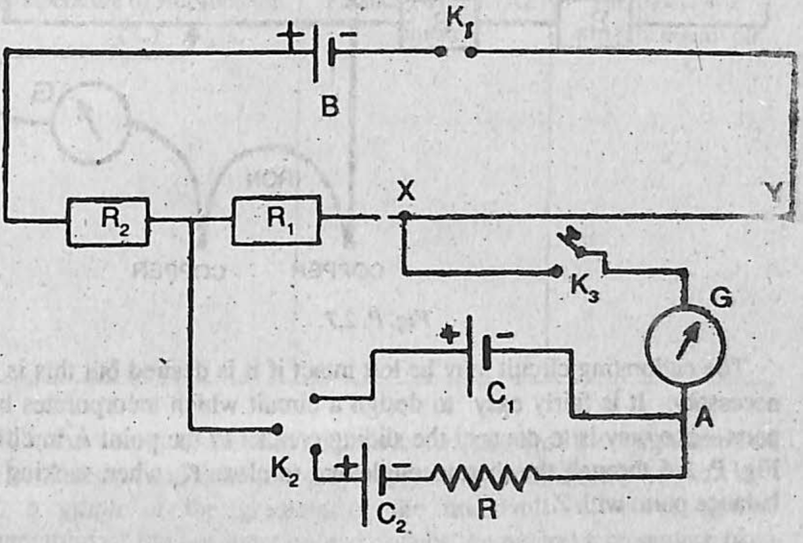


Fig. P. 2.6

Give R_1 and R_2 each a value of 500 *r* ohms. Set K_2 so that the Daniell cell is included in the circuit and then alter the value of R_2 until there is no deflection in the galvanometer on closing the key K_3.

Now set K_2 so that the standard cell is in circuit and make the necessary adjustments to R_2 so that there is no deflection in the galvanometer when K_3 is closed *momentarily*.

The p.d. across R_1 is now equal to the *e.m.f.* of the standard cell. If this be *e* volts, then the p.d. across the wire XY is $\frac{1}{500}$ *e* volts.

Part II. Determination of the Thermoelectric E.M.F's At Various Temperatures of the Hot Junction :

Arrange the thermocouple with its cold junction in ice, if this is available, and its hot junction in its container to a 220 volts mains point with a switch included. Connect it into the circuit shown in Fig. P. 2.7 in which B, K_1, R_1, R_2 and XY are left exactly as they were at the end of the calibration experiment, and T is the thermocouple, G is the galvanometer and Z is the sliding contact.

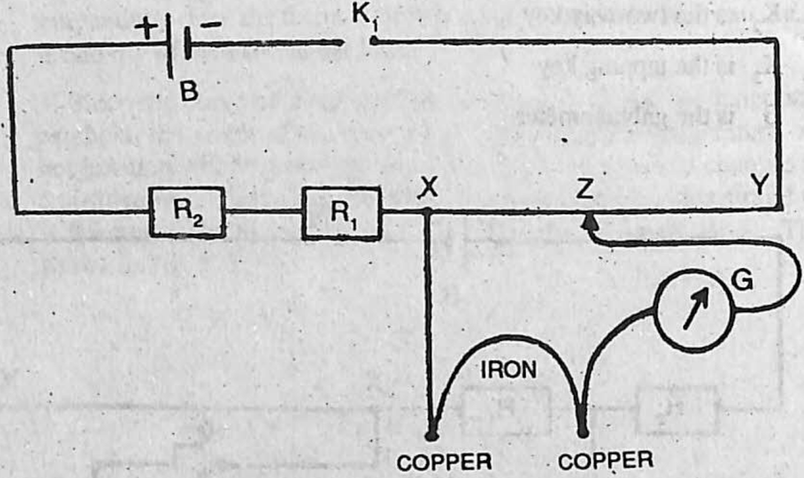


Fig. P. 2.7

The calibrating circuit may be left intact if it is desired but this is not necessary. It is fairly easy to design a circuit which incorporates both parts—one way is to connect the sliding contact to the point A in circuit Fig. P. 2.6 through the thermocouple and to close K_3 when seeking the balance point with Z.

Switch on the current in the heating element and allow the temperature to rise until it is about 40° below the maximum temperature which the thermometer can safely record. The temperature will continue to rise a little and by switching the current on and off it will be possible to adjust the temperature of the hot junction to a value near to the maximum which the thermometer will record.

Find a balance point for the highest temperature possible ; record the length XZ and the temperature. As the hot junction cools, take a series of corresponding observations of the position of the balance point and the temperature, *noting the latter when the balance point has been located, not before.*

Record and Calculation :

Part I

Resistance of Potentiometer wire = ...ohms

Length of Potentiometer wire = ...cm

e.m.f. of standard cell = ...volts

Vaule of R_1 when G gives no deflection, with

standard cell in circuit = ...ohms

Hence P.D. per cm along the wire XY

=.....micro-volts

Part II. Tabulate as follows :

Temperature of Hot Junction (^{0}C)	Balance Position (XZ) in cm	Thermoelectric *e.m.f.* in microvolt

Plot the values of the thermoelectric *e.m.f.* against the temperature of the hot junction and from this graph deduce the neutral temperature. Plot also a graph of the gradient of the microvolt—C^0 curve against temperature of the hot junction and deduce the neutral temperature from this.

Notes :

1. The iron wire used in making the thermocouple may not be pure but may contain some carbon. The amount of this will vary from one specimen to another and this will cause a variation in the value of the neutral temperature.

2. If a standard cell is not available the neutral temperature can be found by using an uncalibrated potentiometer wire and plotting the lengths of XZ against the temperatures of the hot junction. It will still be necessary to have about 1000 *r* ohms in circuit with the accumulator so that the P.D., per cm of the wire is of the right order to give balance points at reasonable positions along XY.

□□

SAMPLE PROJECT 3

Determination of Relative Humidity by Adiabatic Expansion (Expansion Hygrometer).

Hints :

An instructive method for determining the dew point and consequently estimating the relative humidity of the atmosphere is to allow slightly compressed air at room temperature to expand adiabatically. Generally, the water vapour present in the air becomes saturated at the lower temperature after the expansion and mist forms which quickly clears up. One can adjust the initial pressure until condensation just fails to form after expansion and this can perhaps be done to within 2 mm. of mercury.

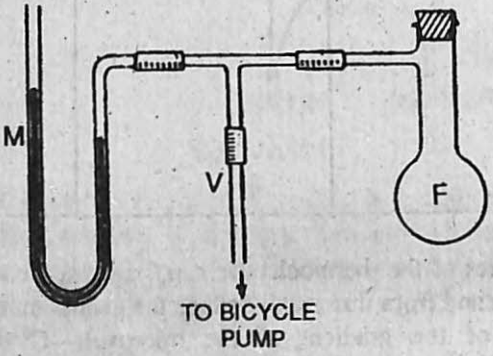


Fig. P. 3.1

The apparatus is simple and can be put together in a few minutes (Fig. P. 3·1). It consists of 250 cm³ flask F closed with a rubber bung which can be removed quickly. The flask has a side tube which is connected by means of short pressure—tubing to a glass T-piece which is connected to a mercury manometer M and a cycle tyre valve V. The air is compressed slowly by means of a bicycle pump and is allowed to cool before expansion is carried out.

Let the initial pressure and temperature be P_1 cm of mercury and T_1 kelvin respectively and the final pressure and temperature be P_2 (atmospheric) and T_2 kelvin For adiabatic expansion

$$T_2 = T_1 \left[\frac{P_2}{P_1}\right]^{\frac{\gamma - 1}{\gamma}}$$

where $\gamma = \frac{C_P}{C_v}$ for air.

If the aqueous S.V.P. at $T_2 = a$, then the water vapour at room temperature $= a.\frac{T_1}{T_2}$ approximately; and hence the relative humidity is calculated *i.e.*,

$$\text{R.H.} = \frac{\text{Actual V. P.}}{\text{Maximum V. P.}} \times 100\%.$$

For an adiabatic change

$$\frac{T^{\frac{\gamma}{\gamma-1}}}{} = KP, \text{ where } K = \text{constant.} \quad ...(1)$$

For small changes we have

$$\frac{\gamma}{\gamma-1}\, T^{\left(\frac{\gamma}{\gamma-1}-1\right)}\delta T = K\,\delta P$$

Substituting for K from (1) we get

$$\delta T = \frac{\gamma-1}{\gamma}\ .\ \frac{T}{P}\ .\ \delta P.$$

Taking $\gamma = 1{\cdot}4$;

$\frac{T}{P} \simeq 4$ and $\delta P = 0{\cdot}2$, we have

$0{\cdot}3^\circ C > \delta T > 0{\cdot}2^\circ C$

with ordinary hygrometers in a school laboratory, the uncertainty in the dew point is of the order of 0·5°C. and this method promises to be, at least, as accurate.

The following is a comparison between Regnault's hygrometer and the above hygrometer carried out under laboratory conditions :

Room temperature = 17·2°C.

Atmospheric Pressure = 76·7 cm of mercury.

Regnault's

S.V.P. (saturated vapour pressure) at 17·2°C = 14·7 mm of Hg.

Dew Point = 15·0°C

S.V.P. at 15·0° C = 12·8 mm of Hg.

$$\text{Relative Humidity} = \frac{12{\cdot}8 \times 100}{14{\cdot}7} = 87$$

Expansion Hygrometer :

Pressure drop = 2·8 cm of Hg.

$P_1 = 76{\cdot}7 + 2{\cdot}8 = 79{\cdot}5$ cm of Hg.

$T_2 = 290{\cdot}2\left(\frac{76{\cdot}7}{72{\cdot}5}\right)^{\frac{2}{7}} = 287{\cdot}4$ kelvin

S.V.P. at 14·4°C = 12·3 mm

Corrected for temperature, the V.P. becomes 12·4 mm.

$$\text{The Relative Humidity} = \frac{12{\cdot}4 \times 100}{14{\cdot}7} = 84\%$$

I think the agreement is good and justifies further attempts at refinement and increasing sensitivity.

□□

SEMI-CONDUCTORS :

The energy possessed by an electron in an atom determines the orbit in which it will move, and in order to jump from an orbit nearer the nucleus to one farther away it must be given the appropriate amount of energy. The quantum theory shows that the process is not continuous but that there are definite restricted zones of energy and these are known as '*bands*'. The outermost electrons in a normal atom constitute the valency electrons and are in the valency band. Conduction of electricity is mainly the result of the movement of electrons and these must usually be even farther away from the nucleus than the valency band. In good conductors, like the metals, the valency band and the conduction band overlap, so that there are always electrons available for conduction. In insulators there is a considerable gap between the minimum of the conduction band and the maximum of the valency band. This is illustrated in Fig. (*i*) and (*ii*) in which (*i*) shows the general case and (*ii*) shows the special case which applies to metals.

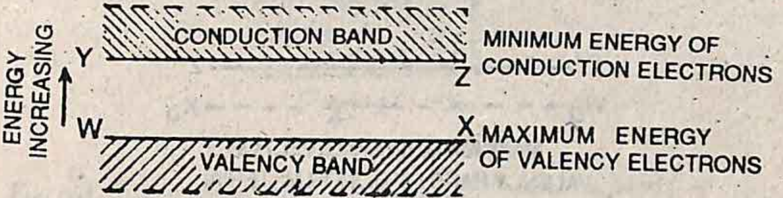

ENERGY INCREASING
CONDUCTION BAND
Y
Z
MINIMUM ENERGY OF CONDUCTION ELECTRONS
W
X
MAXIMUM ENERGY OF VALENCY ELECTRONS
VALENCY BAND

Fig. (i).

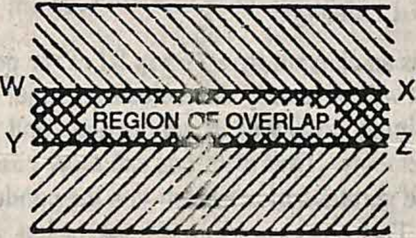


Fig. (ii). Energy levels in a conductor e.g., a metal like copper

In the case of the elements *Germanium* and *Silicon* (Group IV of the Periodic Table) the gap between the bands is too large for electrons to jump unless extreme energies are available, and these materials are therefore non-conductors. If, however, traces of elements are introduced into otherwise pure Germanium or silicon, these impurities can act as "*stepping stones*" between the valency and conduction bands. The processes are as follows :

(i) N-type semi-conductors :

If the impurity is an element from Group V of the periodic table, *e.g.*, *arsenic* or *antimony*, this will have five electrons in its valency band. Moreover, the maximum energy of the valency band or the impurity element is greater than that in the germanium or silicon; and electrons can thus more readily move from this band into the conduction band of the group IV element. The material thus becomes **semi-conducting** and because the conduction is due to the enrichment by *negative ions*, it is known as *N-type*. Some conduction is due to positive ions in this material but *most* is due to electrons and these are referred to as the "*majority carriers*" (In N-type materials). (Fig. (*iii*)).

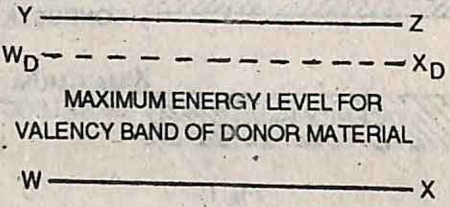


Fig. (iii). N-type semi-conductors

(ii) P-Type Semi-Conductors :

If the impurity is an element from Group III of the periodic table, *e.g.*, *boron* or *indium*, it will have only three electrons in its valency band and moreover, the minimum energy of its conduction band is lower than that of the group IV elements. Thus electrons can more easily jump from the valency band of the germanium or silicon into the conduction band of the boron or indium. This process creates a positive ion, by the loss of the electron, and as this is a '*Vacancy*' for another election it is usually referred to as a "*hole*" and the material is known as '*P-type*' semi-conductor. In such materials most of the conduction is by the *positive holes* and thus in this case the electrons are the *minority carriers*. The process is illustrated in Fig. (*iv*).

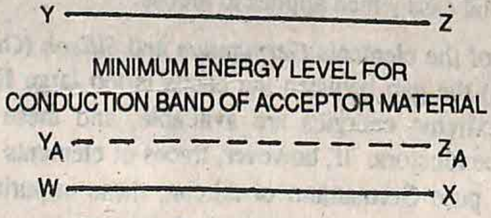

Y
Z
MINIMUM ENERGY LEVEL FOR CONDUCTION BAND OF ACCEPTOR MATERIAL
Y_A
Z_A
W
X

Fig. (iv). P-type Semi-conductors

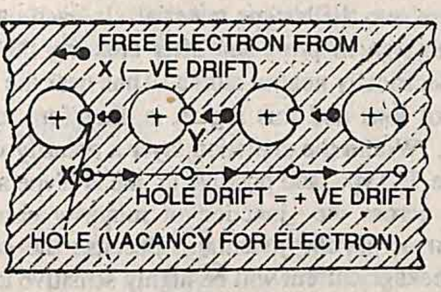


Fig. (v). Semi-conductor electron and hole charge carrier

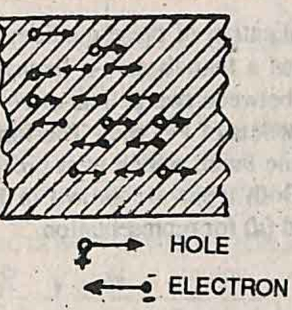


Fig. (vi). Silicon and germanium contain holes (+) and electrons (—)

The effect of a junction :

If a P-type material and an N-type material are put into contact, there will be diffusion at the junction caused by the random movement of the ions, due to thermal agitation, and this will be more marked at higher temperatures. Thus, electrons will diffuse into the P-type material and

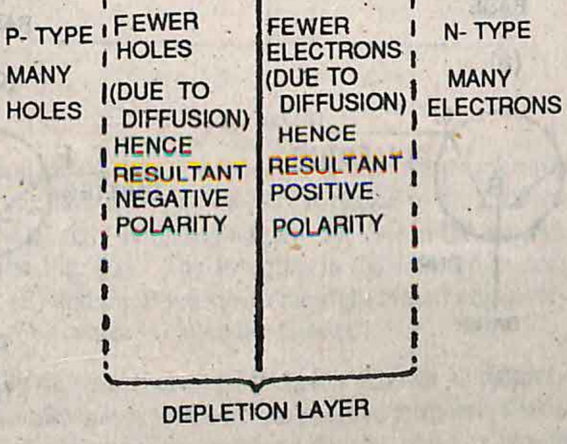


Fig. (vii). Depletion layer

holes will diffuse into the N-type material. In each case these will meet ions of opposite sign in profusion after crossing the junction and will unite to form electrically neutral atoms. Thus near the junction there will be a shortage of ions and this region is, therefore, called a 'depletion layer' (Fig. *vii*). Within the depletion layer a polarity will be established, negative in the P-Type and positive in the N-Type and this will favour the movement across the junction of minority carriers. So there is *leakage current* across the junction. Because the effect is caused by diffusion, the leakage current will be highly sensitive to temperature.

The Transistor :

The practical application of these qualities resulted in the production of a device known as a **transistor**—a '*transfer resistor*'. It may be a thin plate of P-type between two pellets of N-Type, or a thin plate of N-Type between two pellets of P-Type. The former is referred to as an *N-P-N transistor* and the latter, which is at present the more common, the *P-N-P transistor*. Both types are shown in Fig. (*viii*) (*a*) and (*c*) with their symbols (*b*) and (*d*) for representation.

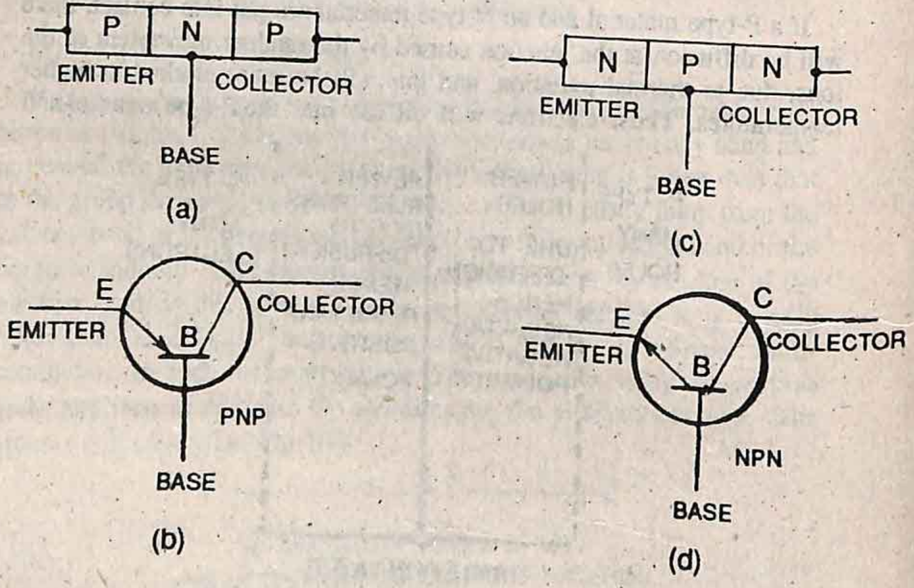


Fig. (viii)

The centre section is called the *base* (B), one of the outside sections—*the emitter* (E), and the other outside section—*the collector* (C).

Operation of PNP Transistor :

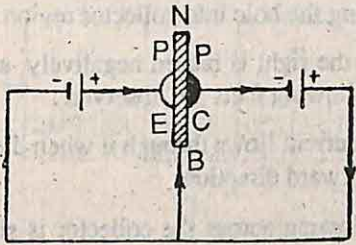


Fig. (ix) (a)

A PNP junction transistor is made by sandwitching two PN germanium or silicon diodes; placed back to back. The centre or N-Type portion is extremely thin in comparison to P-regions.

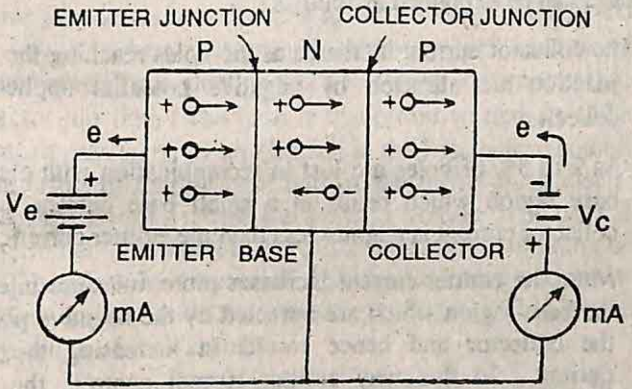


Fig. (ix) (b)

The P-region of the left is connected to the positive terminal and N-region to the negative terminal, *i.e.*, PN is biased in the forward direction while P-region of right is biased negatively, *i.e.*, in the reverse direction as shown in the Fig. (*ix*). The P-region in the forward biased circuit is called emitter (E) and the P-region on the right biased negatively is called collector (C). The centre is called the base (B).

The majority carriers (holes) of P-region (known as emitter) move to the N-region as they are repelled by the positive terminal of battery while the electrons of N-region are attracted by the positive terminal. The holes overcome the barrier and cross the emitter junction into N-region.

As the width of base region is extremely thin, 2 to 5% of the holes recombine with the free electrons of N-region which results, in a small base current, while the remaining holes (95% to 98%) reach the collector junction. The collector is biased negatively and the negative collector voltage aids in sweeping the hole into collector region.

As the P-region at the right is biased negatively, a very small current should flow but the following facts are observed :

(*i*) a substantial current flows through it when the emitter junction is biased in a forward direction,

(*ii*) the current flowing across the collector is slightly less than the emitter current, and

(*iii*) the collector current is a function of emitter current, *i.e.*, with the decrease or increase in the emitter current a corresponding change in the collector current is observed.

The facts can be explained as follows :

(*i*) The collector current increases as the holes reaching the collector junction are attracted by negative potential applied to the collector.

(*ii*) As 2 to 5% of holes are lost in recombination with electrons in base region which result in a small base current, hence the collector current is slightly less than the emitter current.

(*iii*) When the emitter current increases more holes are injected into the base region which are attracted by the negative potential of the collector and hence results in increasing the collector current. In this way emitter current controls the collector current. The control of collector current by the emitter current is analogous to the control of plate current by small grid voltage in a vacuum triode.

Hence we can say that when the emitter is forward biased and collector is negatively biased, a substantial current flows in both the circuits. Since a small emitter voltage of about 0·1 to 0·5 volts permits the flow of an appreciable emitter current, the input power is very small. The collector voltage can be as high as 45 volts, thus permitting relatively large output power.

Besides holes current, another component of current flows from the base region to emitter region due to the flow of electrons. This current is a function of emitter base potential. When the width of base region is very small, the ratio between hole current and electron current is very large and for practical purposes the electron current can be neglected. *Thus only the hole current plays the important role in the operation of PNP transistor.*

NPN Transistor Biasing :

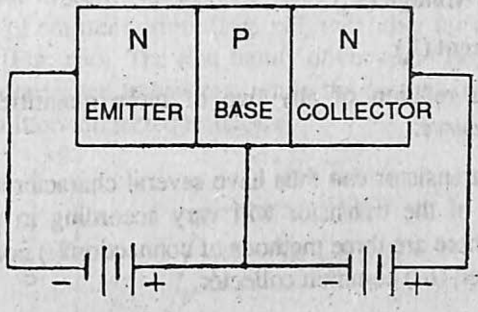


Fig. (x). NPN transistor with biasing potential

As shown in Fig. (*x*) for an amplifying action of NPN transistor, emitter-base junction is biased with a forward voltage and base-collection junction with a reverse voltage. A relatively high current will flow through the emitter-base junction and a relatively low current through the base-collector junction. The base is made thin so that its width is less than the mean path taken by an electron in the base before combining the hole. The effect of narrow base will be the diffusion of electrons into base collector junction, where the applied voltage will draw them to collector terminal. The number of emitter electrons combining with base holes will, therefore, be very small due to which base current is always small while, emitter collector current is large. This explains the *amplifying action* of the transistor.

From the above analysis following points are observed in case of junction transistor :

1. *Holes* are the major charge carriers in the *PNP* junction.

2. *Electrons* are the major charge carriers in the *NPN* junction.

3. In either type of junction transistor the collector current is always less than the emitter current. This is due to the recombination of holes and electrons in base area.

The ratio of collector to emitter current is known as current gain or current amplification factor.

Characteristics of Transistors :

There are variables involved in a transistor. They are (*i*) Emitter current (I_e)

(*ii*) Emitter voltage (V_e)

(*iii*) Collector current (I_c)

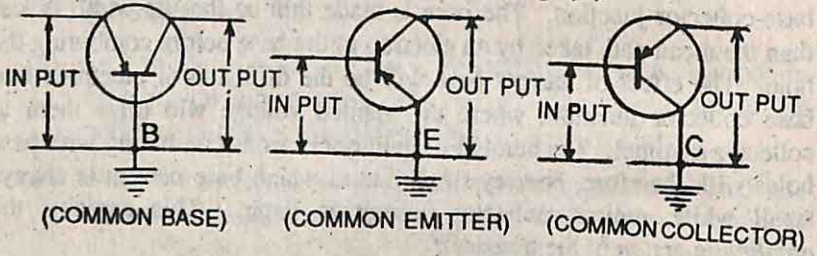
(*iv*) Collector voltage (V_c)

(*v*) Base current (I_b)

A graphical relation of any two of these quantities constitutes a *characteristic curve.*

A junction transistor can thus have several characteristic curves. The characteristics of the transistor will vary according to the methods of connection. There are three methods of connection:(*i*) common base, (*ii*) common emitter, (*iii*) common collector.

As compared to the vacuum tube, base serves the purpose of control grid, collector that of anode and emitter that of cathode. The word 'common' used is to denote the electrode that is common to both the input and output circuits. Common electrode is usually grounded. Therefore for 'common' we can also write the word "*grounded*". All the three types of connections are shown below in Fig. (*xi*).



(COMMON BASE) (COMMON EMITTER) (COMMON COLLECTOR)

Fig. (xi)

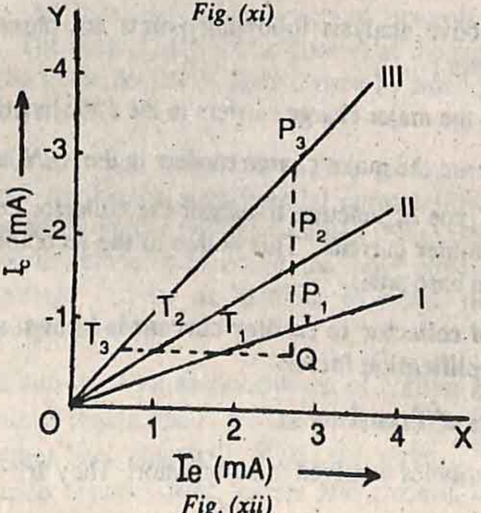


Fig. (xii)

With common base circuit, if we plot a graph between collector current (I_c) and Emitter current (I_e) we get characteristics as shown in Fig. (*xii*).

The most commonly used characteristics of a transistor are those which are drawn in collector current versus collector voltage, one for constant values of emitter current (Fig. *xiii*) and other for constant values of base current (Fig. *xiv*). The first family of curves is generally used for grounded base connected transistors, while the second is generally used for grounded-emitter connected transistor.

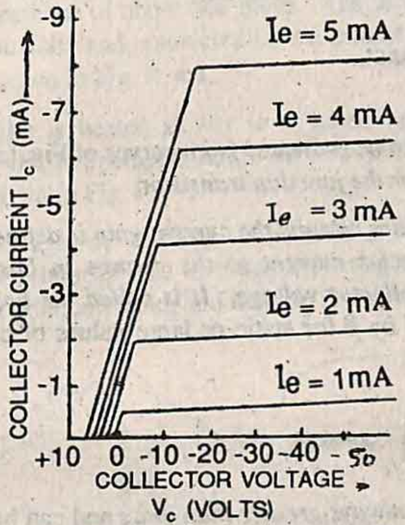


Fig. (xiii) Characteristic curves

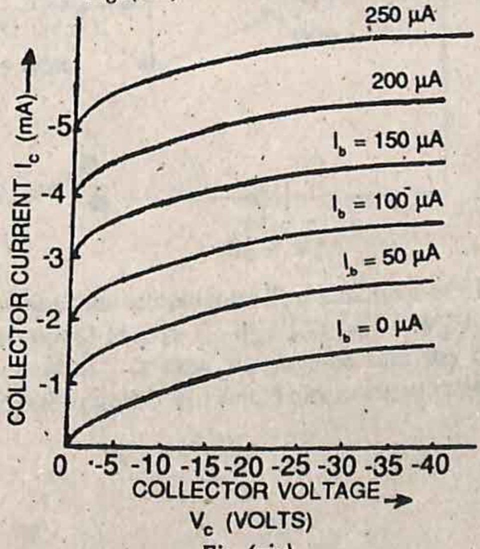


Fig. (xiv)

The characteristics are useful in calculating the *current gain* (**current amplification factor**) of a transistor circuit.

The current gain of a common base transistor circuit is defined as the ratio of the change in collector current to the change in emitter current for constant value of collector voltage. It is denoted by a symbol α, called alpha direct current gain when specified for static or large emitter and collector currents.

$$\text{So } \alpha = \frac{\text{change in the collector current}}{\text{change in emitter current}} \text{ for constant collector voltage}$$

$$= \left(\frac{dI_c}{dI_e}\right)_{V_c} \text{ constant.}$$

The value of α can be estimated from curves of Fig. (*xii*) or (*xiii*). *It is always less than 1 for the junction transistor.*

For common-emitter circuits the current gain is defined as the ratio of the change in collector current to the change in base current for a constant value of collector voltage. It is called the beta direct current gain and is denoted by β for static or large values of collector currents and base currents.

$$\therefore \quad \beta = \left(\frac{dI_c}{dI_b}\right)_{V_c} \text{ constant}$$

The value of β is always greater than unity and can be estimated from Fig. (*xiv*).

□□

SAMPLE PROJECT 4

Measurement of Energy Gaps in a Semi-Conductor

The given project is to get students to measure the temperature variation of resistance of a thermistor, and from the results, to obtain a value for the energy gap W_g between an impurity level and the conduction band. The project involves a number of assumptions but is simple and does show the existence of finite gaps. Quantitatively the results are of the right order and help to make any simple account of band theory more plausible.

The thermistor to be used is a *STC type G 52* which has a room temperature resistance of about 500 ohms. The thermistor is mounted in an oil filled test tube and connected in one arm of a wheatstone bridge. The circuit is shown in Fig. P. 4.1.

The test tube is heated slowly in a water bath and the resistance measured over the temperature range 20°C to about 90°C. The results obtained are shown in Fig. P. 4.2.

Suppose we assume that the semiconductor is *n-type*, that the conductivity is primarily due to electrons being excited from a donor level into the conduction band, and that W_g is the energy gap.

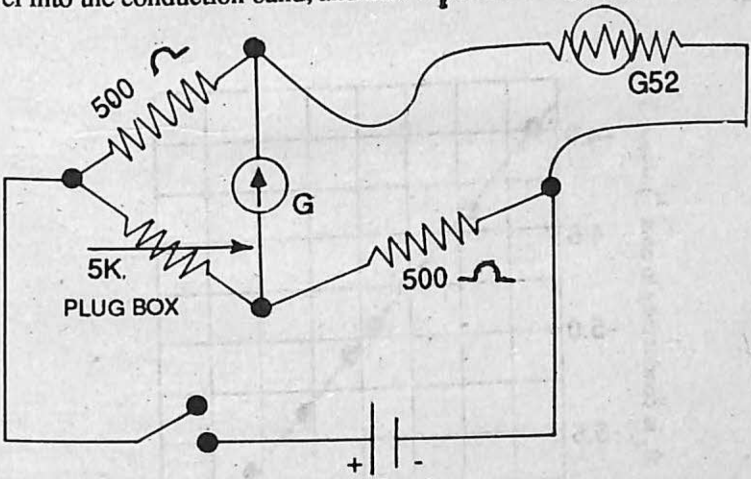


Fig. P. 4.1

Then at an absolute temperature T, the number of excited electrons N_T will be proportional to exp. $(-W_g / kT)$ *i.e.*, $e^{-W_g / kT}$ where k is the Boltzmann constant. If now we assume that the conductivity σ_T is proportional to the number of excited electrons, we would expect

$$\sigma_T \propto e^{-W_g / kT}$$

Thus a graph of $\log_e \sigma_T$ against $\frac{1}{T}$ should be a straight line with a slope of $-W_g/k$.

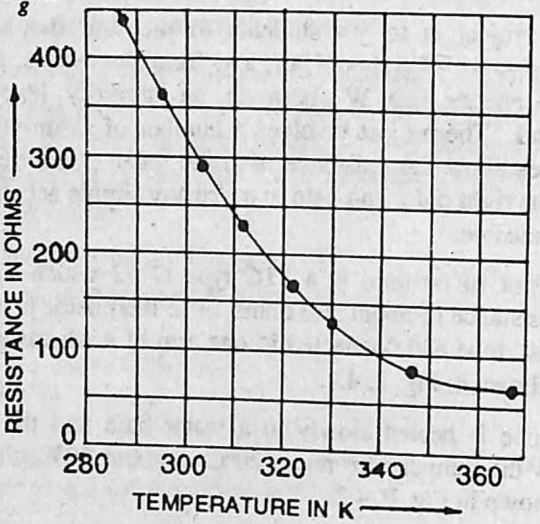


Fig. P.4.2

Using the results plotted in Fig. P. 4.2, this graph is shown in Fig. P. 4.3.

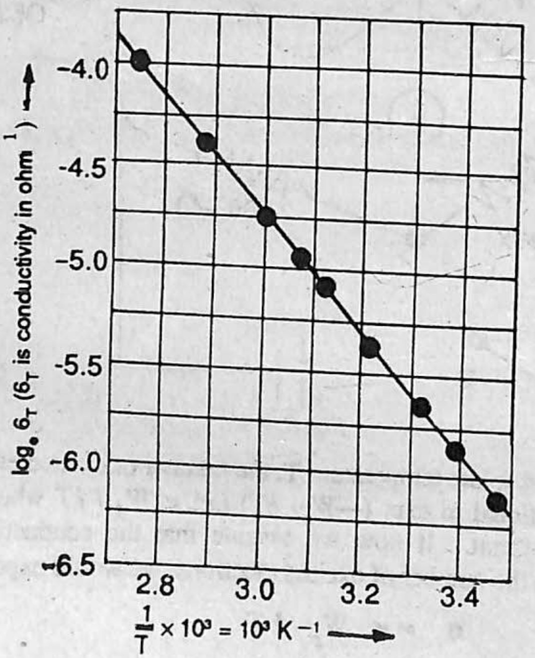


Fig. P.4.3

Putting $k = 1{\cdot}38 \times 10^{-16}$ ergs K^{-1}

$= 0{\cdot}86 \times 10^{-4}$ eV K^{-1},

Fig. P. 4.3 gives a value for

$$W_g \approx 0{\cdot}25\ eV.$$

This compares with a forbidden band in pure germanium of 0·75 *e*V, and in pure silicon of about 1·1 *e*V.

□□

if $x = 0{\cdot}5\ y$ or $x = y$, the graph shows that there is a decrease in illumination of only about 10 per cent from the maximum. Such a decrease at the bottom of the board would hardly be noticeable and could easily be tolerated. It is thus found that the value $x = 0{\cdot}7\ y$ is not critical.

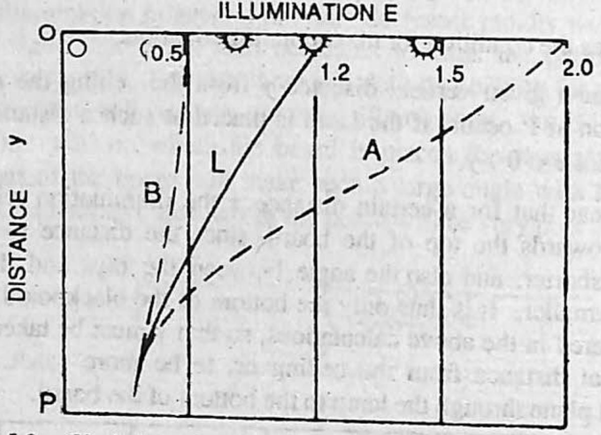


Fig. P 5.3 . [Variation of the illumination with distance y for three different positions A, L and B of the lamp. OA = 0·5 ×OP; OL = 0·7 ×OP; OB=OP]

Fig. P 5.3 shows how the illumination depends on the distance y for three different values of x, namely the value for maximum illumination $x = 0{\cdot}7$ (marked L) and two extreme values $x = 0{\cdot}5$ OP mentioned above (marked A and P respectively). As already concluded, there is very little difference in illumination at the bottom of the board, but it can be seen that position A gives a much better illumination of the upper part than the other positions, while position B gives less but more evenly distributed illumination.

Conclusions :

If y is the vertical distance from a horizontal plane through the tubular lamp to the bottom of the board, the most suitable position for the lamp is between $0{\cdot}5\ y$ and y from the wall, the former extreme giving a better illumination of the upper part, the latter extreme giving a more even distribution of light.

□□

TABLES OF PHYSICAL CONSTANTS

And

COLOUR CODE FOR RADIO RESISTANCES

5. Electromagnetic Spectrum : (Wavelengths)

Wireless Waves			5 metres and above
Infra Red	3×10^{-2} cm	to	7.5×10^{-5} cm
Visible Red	7.5×10^{-5} cm	to	6.5×10^{-5} cm
Visible Orange	6.5×10^{-5} cm	to	5.9×10^{-5} cm
Visible Yellow	5.9×10^{-5} cm	to	5.3×10^{-5} cm
Visible Green	5.3×10^{-5} cm	to	4.9×10^{-5} cm
Visible Blue	4.9×10^{-5} cm	to	4.2×10^{-5} cm
Visible Violet	4.2×10^{-5} cm	to	3.9×10^{-5} cm
Ultra Violet	3.9×10^{-5} cm	to	1.8×10^{-5} cm
Soft X-Rays	2.0×10^{-7} cm	to	1.0×10^{-8} cm
Hard X-Rays	1.0×10^{-8} cm	to	1.0×10^{-9} cm
Gamma Rays	5.0×10^{-9} cm	to	5.0×10^{-10} cm
Cosmic Rays	5.0×10^{-12} cm		

6. Surface Tension of Water : (dynes/cm)

Temperature °C	Surface Tension	Temperature °C	Surface Tension	Temperature °C	Surface Tension
0	75·0	30	70·6	70	63·8
10	73·5	40	68·9	80	62·0
15	72·8	50	67·3	90	60·2
20	72·1	60	65·6	100	58·2

7. Velocity of Sound : (ms^{-1})

Substance	Velocity	Substance	Velocity	Substance	Velocity
Solids (20 ℃)		*Liquids (20 ℃)*		*Gases (0 ℃)*	
Aluminium	5100	Alcohol	1275	Air	331·1
Brass	3400	Mercury	1407	Carbon dioxide	259
Copper	3560	Turpentine	1326	Hydrogen	1262
Glass	5000	Water	1447	Nitrogen	338
Iron	5130			Oxygen	316
Steel	4990			Sulphur dioxide	209
				Water vapour	401

8. E.M.F. of Cells : volts

Cell	E.M.F.	Cell	E.M.F.
Daniell	1·08—1·09	Cadmium at 20°C	1·01854
Leclanche	1·45	Lead accumulator	1·9—2·2
Clark at 15°C	1·433	Edison cell	1·45

9. Electro-Chemical Equivalent of Elements :

Element	Atomic weight	Valency	E.C.E. (g/coulomb)
Copper	63·57	2	0·0003295
Gold	197·2	3	0·006812
Hydrogen	1·0080	1	0:00001045
Lead	207·21	2	0·0010736
Nickel	58·69	3	0·0002027
Oxygen	16·00	2	0·0000829
Silver	107·88	1	0·0011180

10. Specific Resistance and Temperature Coefficient :

Substance	Specific Resistance (ohm-cm)	Temp. coeff. of resistance (per °C)
Brass	$6{\cdot}6 \times 10^{-6}$	10×10^{-4}
Constantan	$49{\cdot}1 \times 10^{-6}$	$(-4 \text{ to } +{\cdot}1) \times 10^{-4}$
Copper	$1{\cdot}78 \times 10^{-6}$	$42{\cdot}8 \times 10^{-4}$
German silver	$26{\cdot}6 \times 10^{-6}$	$(2{\cdot}3—6) \times 10^{-4}$
Iron	$12{\cdot}0 \times 10^{-6}$	62×10^{-4}
Manganin	$44{\cdot}5 \times 10^{-6}$	${\cdot}02—{\cdot}5 \times 10^{-4}$
Lead	$20{\cdot}8 \times 10^{-6}$	$43{\cdot}0 \times 10^{-4}$
Mercury	$95{\cdot}8 \times 10^{-6}$	$8{\cdot}9 \times 10^{-4}$
Nichrome	110×10^{-6}	$3{\cdot}5 \times 10^{-4}$
Phos. Bronze	$5 — 10 \times 10^{-6}$	35×10^{-4}
Platinoid	$34{\cdot}4 \times 10^{-6}$	$2{\cdot}5 \times 10^{-4}$
Platinum	$11{\cdot}0 \times 10^{-6}$	37×10^{-4}
Silver	$1{\cdot}65 \times 10^{-6}$	40×10^{-4}
Nickel	$11{\cdot}8 \times 10^{-6}$	27×10^{-4}
Gold	$2{\cdot}42 \times 10^{-6}$	40×10^{-4}

11. Wire Resistances :

S.W.G. No.	Diameter (mm)	Resistance (ohm/metre)		
		Copper	Constantan (60 Cu, 40 Ni)	Manganin (84 Cu, 4 Ni, 12 Mn)
10	3·25	·0021	·057	·051
12	2·64	·0032	·086	·077
14	2·03	·0054	·146	·131
16	1·63	.0083	·228	·204
18	1·22	·0148	·405	·361
20	0·914	·0260	·722	·645
22	0·711	·0435	1·20	1·07
24	0·559	·070	1·93	1·73
26	0·457	·105	0·89	2·58
28	0·374	·155	4·27	3·82
30	0·315	·222	6·08	5·45
32	0·274	·293	8·02	7·18
34	0·234	·404	11·1	9·9
36	0·193	·590	16·2	14·5
38	0·152	·950	26·0	23·2
40	0·122	1·48	40·6	36·3
42	0·102	2·10	58·5	53·4
44	0·081	3·30	91·4	81·7
46	0·061	5·90	162·5	145·5

12. Magnetic Elements :

Place	Angle of Declination	Angle of Dip	Horizontal component (H) *oersted*
Agra	0°10′E	40°—40′	0·348
Ajmer	....	39°—46′	0·358
Aligarh	0° 20′E	41°—50′	0·346
Allahabad	0° 20′W	37°—10′	0·353
Amristar	....	47°—21.3′	0·30
Bangalore	....	9°—21.2′	0·405
Bareilly	0° 20′E	42°—20′	0·344
Bombay	0° 20′ W	25°—30′	0·376
Calcutta	0° 00′	31°—30′	0·382
Chandausi	0° 30′E	42°—40′	0·343
Dehra Dun	0° 50′E	45°—50′	0·332
Delhi	0° 40′ E	42°—52′	0·345
Hyderabad (Deccan)	......	19°—39.2′	0·397
Gorakhpur	0° 20′ W	39°—40′	0·358
Gwalior	0° 20′ E	39°—00′	0·353
Jaipur	0° 30′ E	40°—30′	0·347
Kanpur	0° 00′	38°—39′	0·363
Khurja	0° 30′ E	42°—10′	0·343
Lucknow	0° 10′ W	40°—00′	0·354
Ludhiana	....	45°—13.3′	0·335
Meerut	0° 40′ E	43°—30′	0·339
Nagpur	....	2° — 09′	0·385
Patna	....	36°—24′	0·373
Varanasi	0° 30′ W	37°—10′	0·364

13. Acceleration Due to Gravity (ms^{-2}) :

Place	Acc. due to gravity (g)	Place	Acc. due to gravity (g)
Agra	9.7906	Indore	9.7860
Ajmer	9.7890	Jaipur	9.7852
Aligarh	9.7808	Kanpur	9.7901
Allahabad	9.7895	Lucknow	9.7900
Amritsar	9.792	Ludhiana	9.792
Bangalore	9.780	Madras	9.7828
Bombay	9.7865	Meerut	9.7915
Calcutta	9.7878	Nagpur	9.7854
Dehradun	9.7907	Patna	9.784
Delhi	9.7915	Varanasi	9.7899
Gorakhpur	9.7905	Pole	9.8322
Gwalior	9.7897	Equator	9.7803
Hyderabad (Deccan)	9.789		

14. Viscosity of Liquids (in poise) :

Substance	Viscosity	Substance	Viscosity
Alcohol (ethyl)	.0119	Olive oil	.98
Alcohol (methyl)	.00591	Turpentine oil	.0149
Benzene	.00649	Water at 0°C	.01793
Caster oil	9.86	Water at 20°C	.01006
Chloroform	.00564	Water at 25°C	.00893
Ether	.00234	Water at 30°C	.00800
Glycerine	8.5	Water at 40°C	.00657
Mercury	.0156	Water at 60°C	.00469
		Water at 100°C	.00284

15. *Densities of Common Substances g cm^{-3} :

Substance	Density	Substance	Density	Substance	Density
Solids		*Liquids*		*Gases*	
Aluminium	2·7	Alcohol	0·80	Air	·00129
Brass	8·6	Benzene	0·88	Carbon dioxide	·00198
Copper	8·89	Ether	0·74	Helium	·000176
Glass (Crown)	2·6	Glycerine	1·26	Hydrogen	·000090
Glass (Flint)	4·0	Lubricating oil	0·91	Steam (100°C)	·00061
Gold	19·3	Mercury	13·60		
Iron (cast)	7·5	Methylated spirit	0·83		
Iron (wrought)	7·9	Turpentine	0·87		
Lead	11·34				
Platinum	21·45				
Silver	10·5				
Steel	7·8				
Zinc	7·1				

16. *Densities of Water and Mercury (g cm^{-3}) :

Temperature °C	Water	Mercury
0	0·9999	13·5955
4	1·0000	13·5856
10	0·997	13·5708
20	0·9982	13·5462
30	0·9957	13·5217
40	0·9922	13·4973
50	0·9881	13·4729
60	0·9832	13·4486
70	0·9778	13·4243
80	0·9718	13·4001
90	0·9653	13·3759
100	0·9584	13·3518
150	0·9170	13·2330
200	0·8630	13·1150
300	0·7000	12·8810

*Multiply by 10^3 to get density in kg m^{-3} :

17. Thermocouples :

Thermocouple	Range of Temperature
Copper—Constantan	upto 300°C
Iron—Nickel	from 300°C to 600°C
Nickel—Chromium	from 600°C to 1000°C
Platinum—Platinum and Rhodium alloy	from 1000°C to 1600°C
Iridium—Iridium and Rubidium alloy	from 1600°C to 2000°C
Tungsten—Molybdenum	from 2000°C to 3000°C

18. Some Properties of Solids :

Substance	Melting Point °C	Specific Heat Cal/gm/°C	Coefficient of Linear expansion $\times 10^{-4}$
Aluminium	657	0.22	26
Bismuth	271	0.0303	12
Copper	1083	0.093	17
Gold	1063	0.0316	14
Iron (cast)	1100	0.119	10.2
Steel	1400	0.11	11.0
Lead	327	0.0305	29.2
Silver	961	0.056	19.2
Brass	900	0.092	18.9
Cork	......	0.49	......
Glass	1000	0.16	......
Platinum	1773	0.032	9

19. Transistors and Crystal Diodes

Type	*No.*
AC 125	PNP
AC 126	PNP
AC 127	PNP
AC 128	PNP
AC 134	PNP
AF 114	PNP
AF 115	PNP
AF 116	PNP
AF 117	PNP

Transistors manufactured by Bharat Electronics Limited (BEL).

OA	70
OA	73
OA	72
OA	79
OA	81
OA	85
OA	91
OA	95
DR	25
DR	100

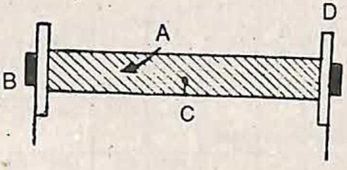
Diodes manufactured by BEL.

20. Colour Code for Radio Resistances

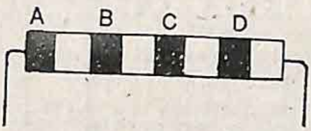
For finding the value of high resistance, generally, carbon resistances used in the radio work are provided in the laboratory. The value of these resistances is indicated by means of a colour code in which the numbers from 0 to 9 are represented by the following colours :

Colour	Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Grey	White
Number	0	1	2	3	4	5	6	7	8	9

Two systems of marking of colours are employed



(a)



(b)

(*i*) The body A, the end B and the dot C are given colours which represent the resistance as will be clear from the following example in which the **Body** is green, **end** is red and **dot** is orange.

To find the resistance, the colour of the *body* gives the first significant figure, the *end* the second significant figure and the *dot* the number of zeros following it. Thus the above resistance comes out to be

Body	End	Dot	
Green	*Red*	*Orange*	
5	2	000	= *52000 ohms*

(*ii*) In the second system the colour of the first ring A on the extreme left represents the first significant figure, second ring B the second significant figure and the third ring C the number of zeros following it. For example, if the first ring is *brown*, second *black* and the third *green*, the given resistance will be

Brown	*Black*	*Green*	
1	0	00000	= 1000000 ohms
			= *1 megohm*

The percentage accuracy or tolerance is represented by the colour of the ring D in both the cases. If it is **silver** in colour the accuracy is ± 10% and if it is **gold** in colour, the tolerance is ± 5%.

☐☐

APPENDIX

Logarithm Tables

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						5	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	36
11	0414	0453	0492	0531	0569						4	8	12	16	20	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	18	22	26	29	33
12	0792	0828	0864	0899	0934						3	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	6	10	13	16	19	23	26	29
						1303	1335	1367	1399	1430	3	7	10	13	16	19	22	25	29
14	1461	1492	1523	1553	1584						3	6	9	12	15	19	22	25	28
						1614	1644	1673	1703	1732	3	6	9	12	14	17	20	23	26
15	1761	1790	1818	1847	1875						3	6	9	11	14	17	20	23	26
						1903	1931	1959	1987	2014	3	6	8	11	14	17	19	22	25
16	2041	2068	2095	2122	2148						3	6	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	16	18	21	23
17	2304	2330	2355	2380	2405						3	5	8	10	13	15	18	20	23
						2430	2455	2480	2504	2529	3	5	8	10	12	15	17	20	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	17	19	21
						2672	2695	2718	2742	2765	2	4	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8

LOGARITHMS

	0	1	2	3	4	5.	6	7	8	9	1 2 3	4 5 6	7 8 9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1 2 3	3 4 5	6 7 8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1 2 3	3 4 5	6 7 8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1 2 2	3 4 5	6 7 7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1 2 2	3 4 5	6 6 7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1 2 2	3 4 5	6 6 7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1 2 2	3 4 5	5 6 7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1 2 2	3 4 5	5 6 7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1 2 2	3 4 5	5 6 7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1 1 2	3 4 4	5 6 7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1 1 2	3 4 4	5 6 7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1 1 2	3 4 4	5 6 6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1 1 2	3 4 4	5 6 6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1 1 2	3 3 4	5 6 6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1 1 2	3 3 4	5 5 6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1 1 2	3 3 4	5 5 6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1 1 2	3 3 4	5 5 6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1 1 2	3 3 4	5 5 6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1 1 2	3 3 4	5 5 6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1 1 2	3 3 4	4 5 6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1 1 2	2 3 4	4 5 6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1 1 2	2 3 4	4 5 6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1 1 2	2 3 4	4 5 5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1 1 2	2 3 4	4 5 5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1 1 2	2 3 4	4 5 5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1 1 2	2 3 4	4 5 5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1 1 2	2 3 3	4 5 5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1 1 2	2 3 3	4 5 5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1 1 2	2 3 3	4 4 5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1 1 2	2 3 3	4 4 5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1 1 2	2 3 3	4 4 5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1 1 2	2 3 3	4 4 5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1 1 2	2 3 3	4 4 5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1 1 2	2 3 3	4 4 5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1 1 2	2 3 3	4 4 5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1 1 2	2 3 3	4 4 5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1 1 2	2 3 3	4 4 5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1 1 2	2 3 3	4 4 5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0 1 1	2 2 3	3 4 4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0 1 1	2 2 3	3 4 4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0 1 1	2 2 3	3 4 4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0 1 1	2 2 3	3 4 4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0 1 1	2 2 3	3 4 4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0 1 1	2 2 3	3 4 4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0 1 1	2 2 3	3 4 4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0 1 1	2 2 3	3 4 4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0 1 1	2 2 3	3 4 4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0 1 1	2 2 3	3 4 4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0 1 1	2 2 3	3 4 4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0 1 1	2 2 3	3 4 4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0 1 1	2 2 3	3 3 4

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	123	456	789
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0 0 1	1 1 1	2 2 2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0 0 1	1 1 1	2 2 2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0 0 1	1 1 1	2 2 2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0 0 1	1 1 1	2 2 2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0 1 1	1 1 2	2 2 2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0 1 1	1 1 2	2 2 2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0 1 1	1 1 2	2 2 2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0 1 1	1 1 2	2 2 2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0 1 1	1 1 2	2 2 3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0 1 1	1 1 2	2 2 3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0 1 1	1 1 2	2 2 3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0 1 1	1 2 2	2 2 3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0 1 1	1 2 2	2 2 3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0 1 1	1 2 2	2 3 3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0 1 1	1 2 2	2 3 3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0 1 1	1 2 2	2 3 3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0 1 1	1 2 2	2 3 3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0 1 1	1 2 2	2 3 3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0 1 1	1 2 2	2 3 3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0 1 1	1 2 2	3 3 3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0 1 1	1 2 2	3 3 3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0 1 1	2 2 2	3 3 3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0 1 1	2 2 2	3 3 3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0 1 1	2 2 2	3 3 4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0 1 1	2 2 2	3 3 4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0 1 1	2 2 2	3 3 4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0 1 1	2 2 3	3 3 4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0 1 1	2 2 3	3 3 4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0 1 1	2 2 3	3 4 4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0 1 1	2 2 3	3 4 4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0 1 1	2 2 3	3 4 4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0 1 1	2 2 3	3 4 4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0 1 1	2 2 3	3 4 4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0 1 1	2 2 3	3 4 4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1 1 2	2 3 3	4 4 5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2285	1 1 2	2 3 3	4 4 5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1 1 2	2 3 3	4 4 5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1 1 2	2 3 3	4 4 5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1 1 2	2 3 3	4 4 5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1 1 2	2 3 3	4 5 5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1 1 2	2 3 4	4 5 5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1 1 2	2 3 4	4 5 5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1 1 2	2 3 4	4 5 6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1 1 2	3 3 4	4 5 6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1 1 2	3 3 4	4 5 6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1 1 2	3 3 4	5 5 6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1 1 2	3 3 4	5 5 6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1 1 2	3 3 4	5 5 6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1 1 2	3 3 4	5 6 6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1 1 2	3 3 4	5 6 6

ANTILOGARITHMS

.	0	1	2	3	4	5	6	7	8	9	123	456	789
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1 1 2	3 4 4	5 6 7
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1 2 2	3 4 5	5 6 7
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1 2 2	3 4 5	5 6 7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1 2 2	3 4 5	5 6 7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1 2 2	3 4 5	6 6 7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1 2 2	3 4 5	6 6 7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1 2 2	3 4 5	6 7 7
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1 2 3	3 4 5	6 7 8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1 2 3	3 4 5	6 7 8
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1 2 3	4 4 5	6 7 8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1 2 3	4 5 5	6 7 8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1 2 3	4 5 6	6 7 8
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1 2 3	4 5 6	7 8 9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1 2 3	4 5 6	7 8 9
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1 2 3	4 5 6	7 8 9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1 2 3	4 5 6	7 8 9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1 2 3	4 5 6	7 8 9
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1 2 3	4 5 6	7 9 10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1 2 3	4 5 7	8 9 10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1 2 3	4 6 7	8 9 10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1 2 3	5 6 7	8 9 10
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1 2 4	5 6 7	8 9 11
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1 2 4	5 6 7	8 10 11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1 2 4	5 6 7	9 10 11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1 3 4	5 6 8	9 10 11
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1 3 4	5 6 8	9 10 12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1 3 4	5 7 8	9 10 12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1 3 4	5 7 8	9 11 12
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1 3 4	5 7 8	10 11 12
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1 3 4	6 7 8	10 11 13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1 3 4	6 7 9	10 11 13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	1 3 4	6 7 9	10 12 13
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2 3 5	6 8 9	11 12 14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2 3 5	6 8 9	11 12 14
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2 3 5	6 8 9	11 13 14
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2 3 5	6 8 10	11 13 15
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2 3 5	7 8 10	12 13 15
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2 3 5	7 8 10	12 13 15
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2 3 5	7 9 10	12 14 16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2 4 5	7 9 11	12 14 16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2 4 5	7 9 11	13 14 16
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2 4 6	7 9 11	13 15 17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2 4 6	8 9 11	13 15 17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2 4 6	8 10 12	14 15 17
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2 4 6	8 10 12	14 16 18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2 4 6	8 10 12	14 16 18
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2 4 6	8 10 12	15 17 19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2 4 6	8 11 13	15 17 19
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2 4 7	9 11 13	15 17 20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2 4 7	9 11 13	16 18 20

NATURAL SINES

Degrees	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Mean Differences				
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	1	2	3	4	5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	·0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	15
5	·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	12	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2232	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	·2419	2436	2452	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	·3256	3273	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	·3746	3762	3778	3795	3811	2827	3843	3859	3875	3891	3	5	8	11	14
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	·5446	5461	6476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	10	12
36	·5878	5892	5906	5920	5934	5848	5962	5976	5990	6004	2	5	7	9	12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10

NATURAL SINES

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1	 2	 3	 4	 5
45	·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2	4	6	8	10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	·7547	7558	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	·9205	9212	9219	9225	9232	9239	9345	9252	9259	9265	1	2	3	4	6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	·9945	9947	9949	9951	9952	8854	9956	9957	9959	9960	0	1	1	1	2
85	·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	·9998	9999	9999	9999	9999	1.000	1.000	1.000	1.000	1.000	0	0	0	0	0
90	1·000														

NATURAL COSINES

[Numbers in difference columns to be subtracted, not added.]

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1	 2	 3	 4	 5
0	1·000	1·000	1·000	1·000	1·000	1·000	9999	9999	9999	9999	0	0	0	0	0
1	·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995	0	0	0	0	0
2	·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987	0	0	0	1	1
3	·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	0	0	1	1	1
4	·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963	0	0	1	1	1
5	·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	0	1	1	1	2
6	·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	0	1	1	1	2
7	·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	0	1	1	2	2
8	·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	0	1	1	2	2
9	·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	0	1	1	2	2
10	·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	1	1	2	2	3
11	·9816	9813	9810	9806	9803	9799	9796	9792	9789	9785	1	1	2	2	3
12	·9781	9778	9774	9770	9767	9763	9759	9755	9751	9748	1	1	2	3	3
13	·9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	1	1	2	3	3
14	·9703	9699	9694	9690	9686	9681	9677	9673	9668	9664	1	1	2	3	4
15	·9659	9655	9650	9646	9641	9636	9632	9627	9622	9617	1	2	2	3	4
16	·9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	1	2	2	3	4
17	·9563	9558	9553	9548	9542	9537	9532	9527	9521	9516	1	2	3	3	4
18	·9511	9505	9500	9494	9489	9483	9478	9472	9466	9461	1	2	3	4	5
19	·9455	9449	9444	9438	9432	9426	9421	9415	9409	9403	1	2	3	4	5
20	·9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	1	2	3	4	5
21	·9336	9330	9323	9317	9311	9304	9298	9291	9285	9278	1	2	3	4	5
22	·9272	9265	9259	9252	9245	9239	9232	9225	9219	9212	1	2	3	4	6
23	·9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	1	2	3	5	6
24	·9135	9128	9121	9114	9107	9100	9092	9085	9078	9070	1	2	4	5	6
25	·9063	9056	9048	9041	9033	9026	9018	9011	9003	8996	1	3	4	5	6
26	·8988	8980	8973	8965	8957	8949	8942	8934	8926	8918	1	3	4	5	6
27	·8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	1	3	4	5	7
28	·8829	8821	8813	8805	8796	8788	8780	8771	8763	8755	1	3	4	6	7
29	·8746	8738	8729	8721	8712	8704	8695	8686	8678	8669	1	3	4	6	7
30	·8660	8652	8643	8634	8625	8616	8607	8599	8590	8581	1	3	4	6	7
31	·8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	2	3	5	6	8
32	·8480	8471	8462	8453	8443	8434	8425	8415	8406	8396	2	3	5	6	8
33	·8387	8377	8368	8358	8348	8339	8329	8320	8310	8300	2	3	5	6	8
34	·8290	8281	8271	8261	8251	8241	8231	8221	8211	8202	2	3	5	7	8
35	·8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	2	3	5	7	8
36	·8090	8080	8070	8059	8049	8039	8028	8018	8007	7997	2	3	5	7	9
37	·7986	7976	7965	7955	7944	7934	7923	7912	7902	7891	2	4	5	7	9
38	·7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	2	4	5	7	9
39	·7771	7760	7749	7738	7727	7716	7705	7694	7683	7672	2	4	6	7	9
40	·7660	7649	7638	7627	7615	7604	7593	7581	7570	7559	2	4	6	8	9
41	·7547	7536	7524	7513	7501	7490	7478	7466	7455	7443	2	4	6	8	10
42	·7431	7420	7408	7396	7385	7373	7361	7349	7337	7325	2	4	6	8	10
43	·7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	2	4	6	8	10
44	·7193	7181	7169	7157	7145	7133	7120	7108	7096	7083	2	4	6	8	10

NATURAL COSINES

[Numbers in difference columns to be subtracted, not added.]

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1 2 3	 4 5
45	·7071	7059	7046	7034	7022	7009	6997	6984	6972	6959	2 4 6	8 10
46	·6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	2 4 6	8 11
47	·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	2 4 6	9 11
48	·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	2 4 7	9 11
49	·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	2 4 7	9 11
50	·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	2 4 7	9 11
51	·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	2 5 7	9 11
52	·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	2 5 7	9 12
53	·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	2 5 7	9 12
54	·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	2 5 7	9 12
55	·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	2 5 7	10 12
56	·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	2 5 7	10 12
57	·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	2 5 7	10 12
58	·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	2 5 7	10 12
59	·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	3 5 8	10 13
60	·5000	4985	4970	4955	4939	4924	4900	4894	4879	4863	3 5 8	10 13
61	·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	3 5 8	10 13
62	·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	3 5 8	10 13
63	·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	3 5 8	10 13
64	·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	3 5 8	11 13
65	·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	3 5 8	11 13
66	·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	3 5 8	11 14
67	·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	3 5 8	11 14
68	·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	3 5 8	11 14
69	·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	3 5 8	11 14
70	·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	3 5 8	11 14
71	·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	3 6 8	11 14
72	·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	3 6 8	11 14
73	·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	3 6 8	11 14
74	·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	3 6 8	11 14
75	·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	3 6 8	11 14
76	·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	3 6 8	11 14
77	·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	3 6 9	11 14
78	·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	3 6 9	11 14
79	·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	3 6 9	11 14
80	·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	3 6 9	12 14
81	·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	3 6 9	12 14
82	·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	3 6 9	12 14
83	·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	3 6 9	12 14
84	·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	3 6 9	12 14
85	·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	3 6 9	12 15
86	·0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	3 6 9	12 15
87	·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	3 6 9	12 15
88	·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	3 6 9	12 15
89	·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	3 6 9	12 15
90	·0000											

NATURAL TANGENTS

Degrees	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Mean Differences	
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	1 2 3	4 5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3 6 9	12 15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3 6 9	12 15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3 6 9	12 15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3 6 9	12 15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3 6 9	12 15
5	·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3 6 9	12 15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3 6 9	12 15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3 6 9	12 15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3 6 9	12 15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3 6 9	12 15
10	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3 6 9	12 15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3 6 9	12 15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3 6 9	12 15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3 6 9	12 15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3 6 9	12 16
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3 6 9	13 16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3 6 9	13 16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3 6 10	13 16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3 6 10	13 16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3 7 10	13 16
20	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3 7 10	13 17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3 7 10	13 17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3 7 10	14 17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3 7 10	14 17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4 7 11	14 18
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4 7 11	14 18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4 7 11	15 18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4 7 11	15 18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4 8 11	15 19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4 8 12	15 19
30	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4 8 12	16 20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4 8 12	16 20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4 8 12	16 20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4 8 13	17 21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4 9 13	17 21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4 9 13	18 22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5 9 14	18 23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5 9 14	18 23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5 9 14	19 24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5 10 15	20 24
40	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5 10 15	20 25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5 10 16	21 26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5 11 16	21 27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6 11 17	22 28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6 11 17	23 29

NATURAL TANGENTS

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences				
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	1	2	3	4	5
45	1.0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	6	12	18	24	30
46	1·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6	12	18	25	31
47	1·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	13	19	25	32
48	1·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7	13	20	27	33
49	1·1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	14	21	28	34
50	1·1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	22	29	36
51	1·2349	2393	2437	2482	2527	2572	2617	2662	2708	2753	8	15	23	30	38
52	1·2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	16	24	31	39
53	1·3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8	16	25	33	41
54	1·3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9	17	26	34	43
55	1·4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	18	27	36	45
56	1·4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	10	19	29	38	48
57	1·5399	5458	5517	5577	5637	5697	5757	5818	5830	5941	10	20	30	40	50
58	1·6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	11	21	32	43	53
59	1·6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	23	34	45	56
60	1·7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	12	24	36	48	60
61	1·8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	13	26	38	51	64
62	1·8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14	27	41	55	68
63	1·9626	9711	9797	9883	9970	2.0057	2.0145	2.0233	2.0323	2.0413	15	29	44	58	73
64	2·0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16	31	47	63	78
65	2·1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17	34	51	68	85
66	2·2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55	73	92
67	2·3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60	79	99
68	2·4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65	87	108
69	2·6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	47	71	95	119
70	2·7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26	52	78	104	131
71	2·9042	9208	9375	9544	9714	9887	3.0061	3.0237	3.0415	3.0595	29	58	87	116	145
72	3·0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32	64	96	129	161
73	3·2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36	72	108	144	180
74	3·4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	81	122	163	204
75	3·7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46	93	139	186	232
76	4·0108	0408	0713	1022	1335	1653	1976	2303	2635	2972	53	107	160	213	267
77	4·3315	3662	4015	4374	4737	5107	5483	5864	6252	6646					
78	4·7046	7453	7867	8288	8716	9152	9594	5·0045	5·0504	5·0970	Mean differences cease to be sufficiently accurate.				
79	5·1446	1929	2422	2924	3435	3955	4486	5026	5578	6140					
80	5·6713	7297	7894	8502	9124	9758	6·0405	6·1066	6·1742	6·2432					
81	6·3138	3859	4596	5350	6122	6912	7720	8548	9395	7·0264					
82	7·1154	2066	3002	3962	4947	5958	6996	8062	9158	8·0285					
83	8·1443	2636	3863	5126	6427	7769	9152	9·0579	9·2052	9·3572					
84	9·5144	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20					
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95					
86	14·30	14·67	15·06	15·46	15·89	16·35	16.83	17·34	17·89	18·46					
87	19·08	19·74	20·45	21·20	22·02	22·90	23.86	24·90	26·03	27·27					
88	28·64	30·14	31·82	33·69	35·80	38·19	40.92	44·07	47·74	52·08					
89	57·29	63·66	71·62	81·85	95·49	114·5	143.2	191·0	286·5	573·0					
90	∞														

LOGARITHMS OF SINES

Degrees	0′ 0°.0	6′ 0°.1	12′ 0°.2	18′ 0°.3	24′ 0°.4	30′ 0°.5	36′ 0°.6	42′ 0°.7	48′ 0°.8	54′ 0°.9	Mean Differences				
											1	2	3	4	5
0	$-\infty$	$\bar{3}$·2419	$\bar{3}$·5429	7190	8439	9408	$\bar{2}$·0200	$\bar{2}$·0870	$\bar{2}$·1450	$\bar{2}$·1961					
1	$\bar{2}$·2419	2832	3210	3558	3880	4179	4459	4723	4971	5206					
2	$\bar{2}$·5428	5640	5842	6035	6220	6397	6567	6731	6889	7041					
3	$\bar{2}$·7188	7330	7468	7602	7731	7857	7979	8098	8213	8326					
4	$\bar{2}$·8436	8543	8647	8749	8849	8946	9042	9135	9226	9315	16	32	48	64	80
5	$\bar{2}$·9403	9489	9573	9655	9736	9816	9894	9970	$\bar{1}$.0046	$\bar{1}$.0120	13	26	39	52	65
6	$\bar{1}$·0192	0264	0334	0403	0472	0539	0605	0670	0734	0797	11	22	33	44	55
7	$\bar{1}$·0859	0900	0981	1040	1099	1157	1214	1271	1326	1381	10	19	29	38	48
8	$\bar{1}$·1436	1489	1542	1594	1646	1697	1747	1797	1847	1895	8	17	25	34	42
9	$\bar{1}$·1943	1991	2038	2085	2131	2176	2221	2266	2310	2353	8	15	23	30	38
10	$\bar{1}$·2397	2439	2482	2524	2565	2606	2647	2687	2727	2767	7	14	20	27	34
11	$\bar{1}$·2806	2845	2883	2921	2959	2997	3034	3070	3107	3143	6	12	19	25	31
12	$\bar{1}$·3179	3214	3250	3284	3319	3353	3387	3421	3455	3488	6	11	17	23	28
13	$\bar{1}$·3521	3554	3585	3618	3650	3682	3713	3745	3775	3806	5	11	16	21	26
14	$\bar{1}$·3837	3867	3897	3927	3957	3986	4015	4044	4073	4102	5	10	15	20	24
15	$\bar{1}$·4130	4158	4186	4214	4242	4269	4296	4323	4350	4377	5	9	14	18	23
16	$\bar{1}$·4403	4430	4456	4482	4508	4533	4559	4584	4609	4634	4	9	13	17	21
17	$\bar{1}$·4659	4684	4709	4733	4757	4781	4805	4829	4853	4876	4	8	12	16	20
18	$\bar{1}$·4900	4923	4946	4969	4992	5015	5037	5060	5082	5104	4	8	11	15	19
19	$\bar{1}$·5126	5148	5170	5192	5213	5235	5256	5278	5299	5320	4	7	11	14	18
20	$\bar{1}$·5341	5361	5382	5402	5423	5443	5463	5484	5504	5523	3	7	10	14	17
21	$\bar{1}$·5543	5563	5583	5602	5621	5641	5660	5679	5698	5717	3	6	10	13	16
22	$\bar{1}$·5736	5754	5773	5792	5810	5828	5847	5865	5883	5901	3	6	9	12	15
23	$\bar{1}$·5919	5937	5954	5972	5990	6007	6024	6042	6059	6076	3	6	9	12	15
24	$\bar{1}$·6093	6110	6127	6144	6161	6177	6194	6210	6227	6243	3	6	8	11	14
25	$\bar{1}$·6259	6276	6292	6308	6324	6340	6356	6371	6387	6403	3	5	8	11	13
26	$\bar{1}$·6418	6434	6449	6465	6480	6495	6510	6526	6541	6556	3	5	8	10	13
27	$\bar{1}$·6570	6585	6600	6615	6629	6644	6659	6673	6687	6702	2	5	7	10	12
28	$\bar{1}$·6716	6730	6744	6759	6773	6787	6801	6814	6828	6842	2	5	7	9	12
29	$\bar{1}$·6856	6869	6883	6896	6910	6923	6937	6950	6863	6977	2	4	7	9	11
30	$\bar{1}$·6990	7003	7016	7029	7042	7055	7068	7080	7093	7106	2	4	6	9	11
31	$\bar{1}$·7118	7131	7144	7156	7168	7181	7193	7205	7218	7230	2	4	6	8	10
32	$\bar{1}$·7242	7254	7266	7278	7290	7302	7314	7326	7338	7349	2	4	6	8	10
33	$\bar{1}$·7361	7373	7384	7396	7407	7419	7430	7442	7453	7464	2	4	6	8	10
34	$\bar{1}$·7476	7487	7498	7509	7520	7531	7542	7553	7564	7575	2	4	6	7	9
35	$\bar{1}$·7586	7597	7607	7618	7629	7640	7650	7661	7671	7682	2	4	5	7	9
36	$\bar{1}$·7692	7703	7713	7723	7734	7744	7754	7764	7774	7785	2	3	5	7	9
37	$\bar{1}$·7795	7805	7815	7825	7835	7844	7854	7864	7874	7884	2	3	5	7	8
38	$\bar{1}$·7893	7903	7913	7922	7932	7941	7951	7960	7970	7979	2	3	5	6	8
39	$\bar{1}$·7989	7998	8007	8017	8026	8035	8044	8053	8063	8072	2	3	5	6	8
40	$\bar{1}$·8081	8090	8099	8108	8117	8125	8134	8143	8152	8161	1	3	4	6	7
41	$\bar{1}$·8169	8178	8187	8195	8204	8213	8221	8230	8238	8247	1	3	4	6	7
42	$\bar{1}$·8255	8264	8272	8280	8289	8297	8305	8313	8322	8330	1	3	4	6	7
43	$\bar{1}$·8338	8346	8354	8362	8370	8378	8386	8394	8402	8410	1	3	4	5	7
44	$\bar{1}$·8418	8426	8433	8441	8449	8457	8464	8472	8480	8487	1	3	4	5	6

LOGARITHMS OF SINES

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences				
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	1	2	3	4	5
45	$\bar{1}$.8495	8502	8510	8517	8525	8532	8540	8547	8555	8562	1	2	4	5	6
46	$\bar{1}$.8569	8577	8584	8591	8598	8606	8613	8620	8627	8634	1	2	4	5	6
47	$\bar{1}$.8641	8648	8655	8662	8669	8676	8683	8690	8697	8704	1	2	3	5	6
48	$\bar{1}$.8711	8718	8724	8731	8738	8745	8751	8758	8765	8771	1	2	3	4	6
49	$\bar{1}$.8778	8784	8791	8797	8804	8810	8817	8823	8830	8836	1	2	3	4	5
50	$\bar{1}$.8843	8849	8855	8862	8868	8874	8880	8887	8893	8899	1	2	3	4	5
51	$\bar{1}$.8905	8911	8917	8923	8929	8935	8941	8947	8953	8959	1	2	3	4	5
52	$\bar{1}$.8965	8971	8977	8983	8989	8995	9000	9006	9012	9018	1	2	3	4	5
53	$\bar{1}$.9023	9029	9035	9041	9046	9052	9057	9063	9069	9074	1	2	3	4	5
54	$\bar{1}$.9080	9085	9091	9096	9101	9107	9112	9118	9123	9128	1	2	3	4	5
55	$\bar{1}$.9134	9139	9144	9149	9155	9160	9165	9170	9175	9181	1	2	3	3	4
56	$\bar{1}$.9186	9191	9196	9201	9206	9211	9216	9221	9226	9231	1	2	3	3	4
57	$\bar{1}$.9236	9241	9246	9251	9255	9260	9265	9270	9275	9279	1	2	2	3	4
58	$\bar{1}$.9284	9289	9294	9298	9303	9308	9312	9317	9322	9326	1	2	2	3	4
59	$\bar{1}$.9331	9335	9340	9344	9349	9353	9358	9362	9367	9371	1	1	2	3	4
60	$\bar{1}$.9375	9380	9384	9388	9393	9397	9401	9406	9410	9414	1	1	2	3	4
61	$\bar{1}$.9418	9422	9427	9431	9435	9439	9443	9447	9451	9455	1	1	2	3	3
62	$\bar{1}$.9459	9463	9467	9471	9475	9479	9483	9487	9491	9495	1	1	2	3	3
63	$\bar{1}$.9499	9503	9506	9510	9514	9518	9522	9525	9529	9533	1	1	2	3	3
64	$\bar{1}$.9537	9540	9544	9548	9551	9555	9558	9562	9566	9569	1	1	2	2	3
65	$\bar{1}$.9573	9576	9580	9583	9587	9590	9594	9597	9601	9604	1	1	2	2	3
66	$\bar{1}$.9607	9610	9614	9617	9621	9624	9627	9631	9634	9637	1	1	2	2	3
67	$\bar{1}$.9640	9643	9647	9650	9653	9656	9659	9662	9666	9669	1	1	2	2	3
68	$\bar{1}$.9672	9674	9678	9681	9684	9687	9690	9693	9696	9699	0	1	1	2	2
69	$\bar{1}$.9702	9704	9707	9710	9713	9716	9719	9722	9724	9727	0	1	1	2	2
70	$\bar{1}$.9730	9733	9735	9738	9741	9743	9746	9749	9751	9754	0	1	1	2	2
71	$\bar{1}$.9757	9759	9762	9764	9767	9770	9772	9775	9777	9780	0	1	1	2	2
72	$\bar{1}$.9782	9785	9787	9789	9792	9794	9797	9799	9801	9804	0	1	1	2	2
73	$\bar{1}$.9806	9808	9811	9813	9815	9817	9820	9822	9824	9826	0	1	1	2	2
74	$\bar{1}$.9828	9831	9833	9835	9837	9839	9841	9843	9845	9847	0	1	1	1	2
75	$\bar{1}$.9849	9851	9853	9855	9857	9859	9861	9863	9865	9867	0	1	1	1	2
76	$\bar{1}$.9869	9871	9873	9875	9876	9878	9880	9882	9884	9885	0	1	1	1	2
77	$\bar{1}$.9887	9889	9891	9892	9894	9896	9897	9899	9901	9902	0	1	1	1	1
78	$\bar{1}$.9904	9906	9907	9909	9910	9912	9913	9915	9916	9918	0	1	1	1	1
79	$\bar{1}$.9919	9921	9922	9924	9925	9927	9928	9929	9931	9932	0	0	1	1	1
80	$\bar{1}$.9934	9935	9936	9937	9939	9940	9941	9943	9944	9945	0	0	1	1	1
81	$\bar{1}$.9946	9947	9949	9950	9951	9952	9953	9954	9955	9956	0	0	1	1	1
82	$\bar{1}$.9958	9959	9960	9961	9962	9963	9964	9965	9966	9967	0	0	1	1	1
83	$\bar{1}$.9968	9968	9969	9970	9971	9972	9973	9974	9975	9975	0	0	0	1	1
84	$\bar{1}$.9976	9977	9978	9978	9979	9980	9981	9981	9982	9983	0	0	0	0	1
85	$\bar{1}$.9983	9984	9985	9985	9986	9987	9987	9988	9988	9989	0	0	0	0	0
86	$\bar{1}$.9989	9990	9990	9991	9991	9992	9992	9993	9993	9994	0	0	0	0	0
87	$\bar{1}$.9994	9994	9995	9995	9996	9996	9996	9996	9997	9997	0	0	0	0	0
88	$\bar{1}$.9997	9998	9998	9998	9998	9999	9999	9999	9999	9999	0	0	0	0	0
89	$\bar{1}$.9999	9999	0.0000	0000	0000	0000	0000	0000	0000	0000					
90	0.0000														

LOGARITHMS OF COSINES

[Numbers in difference columns to be subtracted, not added.]

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences				
											1	2	3	4	5
0	0.0000	0000	0000	0000	0000	0000	0000	0000	0000	$\bar{1}.9999$	0	0	0	0	0
1	$\bar{1}.9999$	9999	9999	9999	9999	9999	9998	9998	9998	9998	0	0	0	0	0
2	$\bar{1}.9997$	9997	9997	9996	9996	9996	9996	9995	9995	9994	0	0	0	0	0
3	$\bar{1}.9994$	9994	9993	9993	9992	9992	9991	9991	9990	9990	0	0	0	0	0
4	$\bar{1}.9989$	9989	9988	9988	9987	9987	9986	9985	9985	9984	0	0	0	0	0
5	$\bar{1}.9983$	9983	9982	9981	9981	9980	9979	9978	9978	9977	0	0	0	0	1
6	$\bar{1}.9976$	9975	9975	9974	9973	9972	9971	9970	9969	9968	0	0	0	1	1
7	$\bar{1}.9968$	9967	9966	9965	9964	9963	9962	9961	9960	9959	0	0	1	1	1
8	$\bar{1}.9958$	9956	9955	9954	9953	9952	9951	9950	9949	9947	0	0	1	1	1
9	$\bar{1}.9946$	9945	9944	9943	9941	9940	9939	9937	9936	9935	0	0	1	1	1
10	$\bar{1}.9934$	9932	9931	9929	9928	9927	9925	9924	9922	9921	0	0	1	1	1
11	$\bar{1}.9919$	9918	9916	9915	9913	9912	9910	9909	9907	9906	0	1	1	1	1
12	$\bar{1}.9904$	9902	9901	9899	9897	9896	9894	9892	9891	9889	0	1	1	1	1
13	$\bar{1}.9887$	9885	9884	9882	9880	9878	9876	9875	9873	9871	0	1	1	1	2
14	$\bar{1}.9869$	9867	9865	9863	9861	9859	9857	9855	9853	9851	0	1	1	1	2
15	$\bar{1}.9849$	9847	9845	9843	9841	9839	9837	9835	9833	9831	0	1	1	1	2
16	$\bar{1}.9828$	9826	9824	9822	9820	9817	9815	9813	9811	9808	0	1	1	2	2
17	$\bar{1}.9806$	9804	9801	9799	9797	9794	9792	9789	9787	9785	0	1	1	2	2
18	$\bar{1}.9782$	9780	9777	9775	9772	9770	9767	9764	9762	9759	0	1	1	2	2
19	$\bar{1}.9757$	9754	9751	9749	9746	9743	9741	9738	9735	9733	0	1	1	2	2
20	$\bar{1}.9730$	9727	9724	9722	9719	9716	9713	9710	9707	9704	0	1	1	2	2
21	$\bar{1}.9702$	9699	9696	9693	9690	9687	9684	9681	9678	9675	0	1	1	2	2
22	$\bar{1}.9672$	9669	9666	9662	9659	9656	9653	9650	9647	9643	1	1	2	2	3
23	$\bar{1}.9640$	9637	9634	9631	9627	9624	9621	9617	9614	9611	1	1	2	2	3
24	$\bar{1}.9607$	9604	9601	9597	9594	9590	9587	9583	9580	9576	1	1	2	2	3
25	$\bar{1}.9573$	9569	9566	9562	9558	9555	9551	9548	9544	9540	1	1	2	2	3
26	$\bar{1}.9537$	9533	9529	9525	9522	9518	9514	9510	9506	9503	1	1	2	3	3
27	$\bar{1}.9499$	9495	9491	9487	9483	9479	9475	9471	9467	9463	1	1	2	3	3
28	$\bar{1}.9459$	9455	9451	9447	9443	9439	9435	9431	9427	9422	1	1	2	3	3
29	$\bar{1}.9418$	9414	9410	9406	9401	9397	9393	9388	9384	9380	1	1	2	3	4
30	$\bar{1}.9375$	9371	9367	9362	9358	9353	9349	9344	9340	9335	1	1	2	3	4
31	$\bar{1}.9331$	9326	9322	9317	9312	9308	9303	9298	9294	9289	1	2	2	3	4
32	$\bar{1}.9284$	9279	9275	9270	9265	9260	9255	9251	9246	9241	1	2	2	3	4
33	$\bar{1}.9236$	9231	9226	9221	9216	9211	9206	9201	9196	9191	1	2	3	3	4
34	$\bar{1}.9186$	9181	9175	9170	9165	9160	9155	9149	9144	9139	1	2	3	3	4
35	$\bar{1}.9134$	9128	9123	9118	9112	9107	9101	9096	9091	9085	1	2	3	4	5
36	$\bar{1}.9080$	9074	9069	9063	9057	9052	9046	9041	9035	9029	1	2	3	4	5
37	$\bar{1}.9023$	9018	9012	9006	9000	8995	8989	8983	8977	8971	1	2	3	4	5
38	$\bar{1}.8965$	8959	8953	8947	8941	8935	8929	8923	8917	8911	1	2	3	4	5
39	$\bar{1}.8905$	8899	8893	8887	8880	8874	8868	8862	8855	8840	1	2	3	4	5
40	$\bar{1}.8843$	8836	8830	8823	8817	8810	8804	8797	8791	8784	1	2	3	4	5
41	$\bar{1}.8778$	8771	8765	8758	8751	8745	8738	8731	8724	8718	1	2	3	5	6
42	$\bar{1}.8711$	8704	8697	8690	8683	8676	8669	8662	8655	8648	1	2	3	5	6
43	$\bar{1}.8641$	8634	8627	8620	8613	8606	8598	8591	8584	8577	1	2	4	5	6
44	$\bar{1}.8569$	8562	8555	8547	8540	8532	8525	8517	8510	8502	1	2	4	5	6

LOGARITHMS OF COSINES

[Numbers in difference columns to be subtracted, not added].

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences				
											1	2	3	4	5
45	$\bar{1}$·8495	8487	8480	8472	8464	8457	8449	8441	8433	8426	1	3	4	5	6
46	$\bar{1}$·8418	8410	8402	8394	8386	8378	8370	8362	8354	8346	1	3	4	5	7
47	$\bar{1}$·8338	8330	8322	8313	8305	8297	8289	8280	8272	8264	1	3	4	6	7
48	$\bar{1}$·8255	8247	8238	8230	8221	8213	8204	8195	8187	8178	1	3	4	6	7
49	$\bar{1}$·8169	8161	8152	8143	8134	8125	8117	8108	8099	8090	1	3	4	6	7
50	$\bar{1}$·8081	8072	8063	8053	8044	8035	8026	8017	8007	7998	2	3	5	6	8
51	$\bar{1}$·7989	7979	7970	7960	7951	7941	7932	7922	7913	7903	2	3	5	6	8
52	$\bar{1}$·7893	7884	7874	7864	7854	7844	7835	7825	7815	7805	2	3	5	7	8
53	$\bar{1}$·7795	7785	7774	7764	7754	7744	7734	7723	7713	7703	2	3	5	7	9
54	$\bar{1}$·7692	7682	7671	7661	7650	7640	7629	7618	7607	7597	2	4	5	7	9
55	$\bar{1}$·7586	7575	7564	7553	7542	7531	7520	7509	7498	7487	2	4	6	7	9
56	$\bar{1}$·7476	7464	7453	7442	7430	7419	7407	7396	7384	7373	2	4	6	8	10
57	$\bar{1}$·7361	7349	7338	7326	7314	7302	7290	7278	7266	7254	2	4	6	8	10
58	$\bar{1}$·7242	7230	7218	7205	7193	7181	7168	7156	7144	7131	2	4	6	8	10
59	$\bar{1}$·7118	7106	7093	7080	7068	7055	7042	7029	7016	7003	2	4	6	9	11
60	$\bar{1}$·6990	6977	6963	6950	6937	6923	6910	6896	6883	6869	2	4	7	9	11
61	$\bar{1}$·6856	6842	6828	6814	6801	6787	6773	6759	6744	6730	2	5	7	9	12
62	$\bar{1}$·6716	6702	6687	6673	6659	6644	6629	6615	6600	6585	2	5	7	10	12
63	$\bar{1}$·6570	6556	6541	6526	6510	6495	6480	6465	6449	6434	3	5	8	10	13
64	$\bar{1}$·6418	6403	6387	6371	6356	6340	6324	6308	6292	6276	3	5	8	11	13
65	$\bar{1}$·6259	6243	6227	6210	6194	6177	6161	6144	6127	6110	3	6	8	11	14
66	$\bar{1}$·6093	6076	6059	6042	6024	6007	5990	5972	5954	5937	3	6	9	12	15
67	$\bar{1}$·5919	5901	5883	5865	5847	5828	5810	5792	5773	5754	3	6	9	12	15
68	$\bar{1}$·5736	5717	5698	5679	5660	5641	5621	5602	5583	5563	3	6	10	13	16
69	$\bar{1}$·5543	5523	5504	5484	5463	5443	5423	5402	5382	5361	3	7	10	14	17
70	$\bar{1}$·5341	5320	5299	5278	5256	5235	5213	5192	5170	5148	4	7	11	14	18
71	$\bar{1}$·5126	5104	5082	5060	5037	5015	4992	4969	4946	4923	4	8	11	15	19
72	$\bar{1}$·4900	4876	4853	4829	4805	4781	4757	4733	4709	4684	4	8	12	16	20
73	$\bar{1}$·4659	4634	4609	4584	4559	4533	4508	4482	4456	4430	4	9	13	17	21
74	$\bar{1}$·4403	4377	4350	4323	4296	4269	4242	4214	4186	4158	5	9	14	18	23
75	$\bar{1}$·4130	4102	4073	4044	4015	3986	3957	3927	3897	3867	5	10	15	20	24
76	$\bar{1}$·3837	3806	3775	3745	3713	3682	3650	3618	3586	3554	5	11	16	21	26
77	$\bar{1}$·3521	3488	3455	3421	3387	3353	3319	3284	3250	3214	6	11	17	23	28
78	$\bar{1}$·3179	3143	3107	3070	3034	2997	2959	2921	2883	2845	6	12	19	25	31
79	$\bar{1}$·2806	2767	2727	2687	2647	2606	2565	2524	2482	2439	7	14	20	27	34
80	$\bar{1}$·2397	2353	2310	2266	2221	2176	2131	2085	2038	1991	8	15	23	30	38
81	$\bar{1}$·1943	1895	1847	1797	1747	1697	1646	1594	1542	1489	8	17	25	34	42
82	$\bar{1}$·1436	1381	1326	1271	1214	1157	1099	1040	0981	0920	10	19	29	38	48
83	$\bar{1}$·0859	0797	0734	0670	0605	0539	0472	0403	0334	0264	11	22	33	44	55
84	$\bar{1}$·0192	0120	0046	$\bar{2}$.9970	$\bar{2}$.9894	$\bar{2}$.9816	$\bar{2}$·9736	$\bar{2}$·9655	$\bar{2}$.9573	$\bar{2}$·9489	13	26	39	52	65
85	$\bar{2}$·9403	9315	9226	9135	9042	8946	8849	8749	8647	8543	16	32	48	64	80
86	$\bar{2}$·8436	8326	8213	8098	7979	7857	7731	7602	7468	7330					
87	$\bar{2}$·7188	7041	6889	6731	6567	6397	6220	6035	5842	5640					
88	$\bar{2}$·5428	5206	4971	4723	4459	4179	3880	3558	3210	2832					
89	$\bar{2}$·2419	1961	1450	0870	0200	$\bar{3}$.9408	$\bar{3}$·8439	$\bar{3}$·7190	$\bar{3}$.5429	$\bar{3}$·2419					
90	∞														

LOGARITHMS OF TANGENTS

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences				
											1	2	3	4	5
0	—∞	$\bar{3}$·2419	$\bar{3}$·5429	$\bar{3}$.7190	$\bar{3}$.8439	$\bar{3}$.9409	$\bar{2}$·0200	$\bar{2}$.0870	$\bar{2}$·1450	$\bar{2}$·1962					
1	$\bar{2}$·2419	2833	3211	3559	3881	4181	4461	4725	4973	5208					
2	$\bar{2}$·5431	5643	5845	6038	6223	6401	6571	6736	6894	7046					
3	$\bar{2}$·7194	7337	7475	7609	7739	7865	7988	8107	8223	8336					
4	$\bar{2}$·8446	8554	8659	8762	8862	8960	9056	9150	9241	9331	16	32	48	64	81
5	$\bar{2}$·9420	9506	9591	9674	9756	9836	9915	9992	$\bar{1}$.0068	$\bar{1}$.0143	13	26	40	53	66
6	$\bar{1}$·0216	0289	0360	0430	0499	0567	0633	0699	0764	0828	11	22	34	45	56
7	$\bar{1}$·0891	0954	1015	1076	1135	1194	1252	1310	1367	1423	10	20	29	39	49
8	$\bar{1}$·1478	1533	1587	1640	1693	1745	1797	1848	1898	1948	9	17	26	35	43
9	$\bar{1}$·1997	2046	2094	2142	2189	2236	2282	2328	2374	2419	8	16	23	31	39
10	$\bar{1}$·2463	2507	2551	2594	2637	2680	2722	2764	2805	2846	7	14	21	28	35
11	$\bar{1}$·2887	2927	2967	3006	3046	3085	3123	3162	3200	3237	6	13	19	26	32
12	$\bar{1}$·3275	3312	3349	3385	3422	3458	3493	3529	3564	3599	6	12	18	24	30
13	$\bar{1}$·3634	3668	3702	3736	3770	3804	3837	3870	3903	3935	6	11	17	22	28
14	$\bar{1}$·3968	4000	4032	4064	4095	4127	4158	4189	4220	4250	5	10	16	21	26
15	$\bar{1}$·4281	4311	4341	4371	4400	4430	4459	4488	4517	4646	5	10	15	20	25
16	$\bar{1}$·4575	4603	4632	4660	4688	4716	4744	4771	4799	4826	5	9	14	19	23
17	$\bar{1}$·4853	4880	4907	4934	4961	4987	5014	5040	5066	5092	4	9	13	18	22
18	$\bar{1}$·5118	5143	5169	5195	5220	5245	5270	5295	5320	5345	4	8	13	17	21
19	$\bar{1}$·5370	5394	5419	5443	5467	5491	5516	5539	5563	5587	4	8	12	16	20
20	$\bar{1}$·5611	5634	5658	5681	5704	5727	5750	5773	5796	5819	4	8	12	15	19
21	$\bar{1}$·5842	5864	5887	5909	5932	5954	5976	5998	6020	6042	4	7	11	15	19
22	$\bar{1}$·6064	6086	6108	6129	6151	6172	6194	6215	6236	6257	4	7	11	14	18
23	$\bar{1}$·6279	6300	6321	6341	6362	6383	6404	6424	6445	6465	3	7	10	14	17
24	$\bar{1}$·6486	6506	6527	6547	6567	6587	6607	6627	6647	6667	3	7	10	13	17
25	$\bar{1}$·6687	6706	6726	6746	6765	6785	6804	6824	6843	6863	3	7	10	13	16
26	$\bar{1}$·6882	6901	6920	6939	6958	6977	6996	7015	7034	7053	3	6	9	13	16
27	$\bar{1}$·7072	7090	7109	7128	7146	7165	7183	7202	7220	7238	3	6	9	12	15
28	$\bar{1}$·7257	7275	7293	7311	7330	7348	7366	7384	7402	7420	3	6	9	12	15
29	$\bar{1}$·7438	7455	7473	7491	7509	7526	7544	7562	7579	7597	3	6	9	12	15
30	$\bar{1}$·7614	7632	7649	7667	7684	7701	7719	7736	7753	7771	3	6	9	12	14
31	$\bar{1}$·7788	7805	7822	7839	7856	7873	7890	7907	7924	7941	3	6	9	11	14
32	$\bar{1}$·7958	7975	7992	8008	8025	8042	8059	8075	8092	8109	3	6	8	11	14
33	$\bar{1}$·8125	8142	8158	8175	8191	8208	8224	8241	8257	8274	3	5	8	11	14
34	$\bar{1}$·8290	8306	8323	8339	8355	8371	8388	8404	8420	8436	3	5	8	11	14
35	$\bar{1}$·8452	8468	8484	8501	8517	8533	8549	8565	8581	8597	3	5	8	11	13
36	$\bar{1}$·8613	8629	8644	8660	8676	8692	8708	8724	8740	8755	3	5	8	11	13
37	$\bar{1}$·8771	8787	8803	8818	8834	8850	8865	8881	8897	8912	3	5	8	10	13
38	$\bar{1}$·8928	8944	8959	8975	8990	9006	9022	9037	9053	9068	3	5	8	10	13
39	$\bar{1}$·9084	9099	9115	9130	9146	9161	9176	9192	9207	9223	3	5	8	10	13
40	$\bar{1}$·9238	9254	9269	9284	9300	9315	9330	9346	9361	9376	3	5	8	10	13
41	$\bar{1}$·9392	9407	9422	9438	9453	9468	9483	9499	9514	9529	3	5	8	10	13
42	$\bar{1}$·9544	9560	9575	9590	9605	9621	9636	9651	9666	9681	3	5	8	10	13
43	$\bar{1}$·9697	9712	9727	9742	9757	9772	9788	9803	9818	9833	3	5	8	10	13
44	$\bar{1}$·9848	9864	9879	9894	9909	9924	9939	9955	9970	9985	3	5	8	10	13

LOGARITHMS OF TANGENTS

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences				
											1	2	3	4	5
45	·0000	0015	0030	0045	0061	0076	0091	0106	0121	0136	3	5	8	10	13
46	·0152	0167	0182	0197	0212	0228	0243	0258	0273	0288	3	5	8	10	13
47	·0303	0319	0334	0349	0364	0379	0395	0410	0425	0440	3	5	8	10	13
48	·0456	0471	0486	0501	0517	0532	0547	0562	0578	0593	3	5	8	10	13
49	·0608	0624	0639	0654	0670	0685	0700	0716	0731	0746	3	5	8	10	13
50	·0762	0777	0793	0808	0824	0839	0854	0870	0885	0901	3	5	8	10	13
51	·0916	0932	0947	0963	0978	0994	1010	1025	1041	1056	3	5	8	10	13
52	·1072	1088	1103	1119	1135	1150	1166	1182	1197	1213	3	5	8	10	13
53	·1229	1245	1260	1276	1292	1308	1324	1340	1356	1371	3	5	8	11	13
54	·1387	1403	1419	1435	1451	1467	1483	1499	1516	1532	3	5	8	11	13
55	·1548	1564	1580	1596	1612	1629	1645	1661	1677	1694	3	5	8	11	14
56	·1710	1726	1743	1759	1776	1792	1809	1825	1842	1858	3	5	8	11	14
57	·1875	1891	1908	1925	1941	1958	1975	1992	2008	2025	3	6	8	11	14
58	·2042	2059	2076	2093	2110	2127	2144	2161	2178	2195	3	6	9	11	14
59	·2212	2229	2247	2264	2281	2299	2316	2333	2351	2368	3	6	9	12	14
60	·2386	2403	2421	2438	2456	2474	2491	2509	2527	2545	3	6	9	12	15
61	·2562	2580	2598	2616	2634	2652	2670	2689	2707	2725	3	6	9	12	15
62	·2743	2762	2780	2798	2817	2835	2854	2872	2891	2910	3	6	9	12	15
63	·2928	2947	2966	2985	3004	3023	3042	3061	3080	3099	3	6	9	13	16
64	·3118	3137	3157	3176	3196	3215	3235	3254	3274	3294	3	6	10	13	16
65	·3313	3333	3353	3373	3393	3413	3433	3453	3473	3494	3	7	10	13	17
66	·3514	3535	3555	3576	3596	3617	3638	3659	3679	3700	3	7	10	14	17
67	·3721	3743	3764	3785	3806	3828	3849	3871	3892	3914	4	7	11	14	18
68	·3936	3958	3980	4002	4024	4046	4068	4091	4113	4136	4	7	11	15	19
69	·4158	4181	4204	4227	4250	4273	4296	4319	4342	4366	4	8	12	15	19
70	·4389	4413	4437	4461	4484	4509	4533	4557	4581	4606	4	8	12	16	20
71	·4630	4655	4680	4705	4730	4755	4780	4805	4831	4857	4	8	13	17	21
72	·4882	4908	4934	4960	4986	5013	5039	5066	5093	5120	4	9	13	18	22
73	·5147	5174	5201	5229	5256	5284	5312	5340	5368	5397	5	9	14	19	23
74	·5425	5454	5483	5512	5541	5570	5600	5629	5659	5689	5	10	15	20	25
75	·5719	5750	5780	5811	5842	5873	5905	5936	5968	6000	5	10	16	21	26
76	·6032	6065	6097	6130	6163	6196	6230	6264	6298	6332	6	11	17	22	28
77	·6366	6401	6436	6471	6507	6542	6578	6615	6651	6688	6	12	18	24	30
78	·6725	6763	6800	6838	6877	6915	6954	6904	7033	7073	6	13	19	26	32
79	·7113	7154	7195	7236	7278	7320	7363	7406	7449	7493	7	14	21	28	35
80	·7537	7581	7626	7672	7718	7764	7811	7858	7906	7954	8	16	23	31	39
81	·8003	8052	8102	8152	8203	8255	8307	8360	8413	8467	9	17	26	35	43
82	·8522	8577	8633	8690	8748	8806	8865	8924	8985	9046	10	20	29	39	49
83	·9109	9172	9236	9301	9367	9433	9501	9570	9640	9711	11	22	34	45	56
84	·9784	9857	9932	1·0008	1·0085	1·0164	1·0244	1·0326	1·0409	1·0494	13	26	40	53	66
85	1·0580	0669	0759	0850	0944	1040	1138	1238	1341	1446	16	32	48	64	81
86	1·1554	1664	1777	1893	2012	2135	2261	2391	2525	2663					
87	1·2806	2954	3106	3264	3429	3599	3777	3962	4155	4357					
88	1·4569	4792	5027	5275	5539	5819	6119	6441	6789	7167					
89	1·7581	8038	8550	9130	9800	2·0591	2·1561	2·2810	2·4571	2·7581					